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The Variability of
PAPER BIRCH
Seed Production, Dispersal, and Germination

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The Variability of PAPER BIRCH Seed Production, Dispersal, and Germination

PAPER BIRCH trees are generally considered prolific seeders that produce at least some seed every year and very large crops of seed periodically. Seed dispersal is widely assumed to begin in early fall and to continue through the winter months. Germinative capacity has been assumed to be fairly low.

However, observations taken during the course of several studies of natural regeneration have provided some new information about paper birch seed-crop characteristics for three widely-separated stands in the Northeast. These observations, coupled with published information, revealed appreciable variation among years in paper birch seed crops as well as some important deviations from the commonly accepted beliefs.

Seed Production

Occasionally huge crops of paper birch seeds blanket some areas with millions of seeds. In a 70-year-old pure paper birch stand in northwestern Massachusetts, the 1955 seed crop was estimated to average about 36 million seeds per acre. In the White Mountain area of New Hampshire, the 1958 seed crop was estimated at about 26 million paper birch seeds per acre in a stand of northern hardwoods about 70 to 75 years old that contained an appreciable amount of paper birch. In eastern Maine, a 70-year-old stand composed largely of paper birch, but including smaller amounts of red maple, aspen, and other species, produced an estimated 17 million paper birch seeds per acre in 1960.

But such large numbers are more likely to be the exception rather than the rule. For example, the Maine stand mentioned above produced only about 1,300,000 seeds per acre in 1958 and 800,000 per acre in 1959.

Frequency of Good Seed Years

Since seed production can vary so greatly from year to year, knowledge of the cyclic occurrence of good seed years can be of great value in planning for natural regeneration.

The *Woody Plant Seed Manual (19)* states that good seed crops (in contrast to light crops) occur almost every year. But published reports in the Northeast and the Lake States suggest that the frequency of reasonably productive seed years is probably about every other year. Between 1957 and 1960, medium[1] or better seed crops were reported for New Hampshire, Massachusetts, and Connecticut about 50 percent of the time; and for Maine and Vermont about 75 percent of the time *(1, 2, 3, 4)*. Good[1] or better crops of paper birch seed were reported about 50 percent of the time in northern

[1]A *medium* crop is defined as: some seeds on all trees, many on some trees (up to 75 percent).

A *good* crop in the Lake States is defined as 61 to 90 percent of a full crop. In this paper, good crops in the Lake States and medium crops in the Northeast are considered to be about equal.

A *bumper* crop is defined as 91 to 100 percent of a full crop.

Minnesota and northeastern Wisconsin between 1949 and 1962 *(5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18).*

These reports cited above, in addition to revealing certain moderate differences in seed crops among reporting areas, also show that there are variations within individual reporting areas. Thus, while the 1959 crop of paper birch seed in northern Maine was rated as medium, a smaller crop was reported in the rest of the State. Similarly, the 1960 seed crop in northern Minnesota ranged from less than good up to bumper.[1]

Because of these variations in the frequency of medium-or-better seed crops, seed-crop data for a very extensive area are suitable only for general use. When seed-crop data are to be used for a specific purpose such as seed collection or planning a regeneration cut, then they should be gathered in the same local area in which they are to be used.

Time of Seed Dispersal

Knowing when seed dispersal occurs is essential if full advantage is to be taken of the seed crop. The *Woody-Plant Seed Manual* states that seed dispersal takes place from September 1 to April 1. But this is too broad a period to be useful in timing regeneration measures. Information about the proportion of the total seedfall by month of dispersal would be more helpful. Knowing when the bulk of the seed usually falls would suggest the approximate date by which all needed seedbed-preparation treatments should be completed.

In the Maine stand previously described, the time of seed dispersal was found to vary from year to year. In 1958 nearly two-thirds of the total seedfall was dispersed in October; in 1959 and 1960 more than half fell in August. The lowest proportion of the total seed crop was dispersed consistently in the December-spring period (table 1).

In the New Hampshire stand almost two-thirds of the 1958 seed crop was dispersed in October (table 1). And seedfall of paper birch has been observed here as early as July 4.

There appears to be no relationship between time of dispersal and size of seed crop; and in both the Maine and New Hampshire stands the bulk of the seed was dispersed every year before the ground was snow-covered. There is an advantage in this: seed dispersed on prepared seedbeds before snow falls will be held in place; seed falling on snow-covered seedbeds might be blown off.

Table 1.—Paper birch seed dispersal in percentage of total seedfall, by period o dispersal, stand location, and year; and estimated total numbers of seeds per acr

Stand location and year	Aug.	Sept.	Oct.	Nov.	Dec.-spring	Total No. seed per acre
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Millions*
Maine, 1958	6	13	63	14	4	1.3
Maine, 1959	58	25	13	3	1	0.8
Maine, 1960	51	13	20	14	2	16.8
New Hampshire, 1958	—	7	63	28	2	26.0

Table 2. — Germinative capacity of paper birch seed by year and seedfall period; Penobscot Experimental Forest, Maine, 1958-1960[1]

Period	1958	1959	1960
	Percent	*Percent*	*Percent*
August	0	22	75
September	1	20	78
October	11	41	74
November	24	32	80
December-spring	34	18	79
Weighted average[2]	13	24	77

[1]The seeds were stratified for 30, 51, and 35 days in 1958, 1959, and 1960 respectively, and the durations of the tests were 45, 40, and 20 days.

[2]The weighted averages were determined by combining the germination data from proportionate samples taken in each month or period of seedfall.

Germination

Results from germination tests suggest that there is a relationship between abundance of seed and its germinative capacity. In the two poor years 1958 and 1959 in the Maine stand, germinative capacity — the percentage of seed germinating regardless of time — was low, averaging 13 and 24 percent respectively (table 2). In the bumper year 1960 the germinative capacity averaged 77 percent — significantly better than the germinative capacity for either of the two previous years.

The pattern of germination (data for all seedfall periods combined) varied considerably between the seed crop of 1960 and the crops of 1958 and 1959 (fig. 1). In 1960 the first germinates appeared 4 days after the start of the germination test. Germination continued at a rapid rate during the next 5 days and then tapered off until, on the twentieth day, germination stopped. Thus for 1960 the germinative energy[2] was estimated at 71 percent in 9 days.

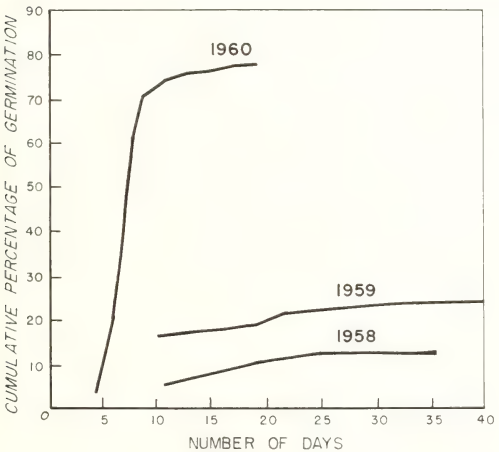

Figure 1. — Paper birch seed produced in the bumper year of 1960 germinated faster and better than that produced in the relatively poor seed years of 1958 and 1959. Data for all seedfall periods are combined.

In 1958 and 1959, germination counts were not made until the tenth day after the start of the test and thereafter only at irregular

[2]In this paper, *germinative energy* is defined as the cumulative percentage of germination and the number of days up to the point where daily germination drops below 5 percent.

and long intervals. For this reason true germinative energy cannot be determined. However, the data for these 2 years do show a much more gradual increase in cumulative percentage of germination than in 1960, and a longer period of germination (fig. 1). These data indicate that germinative energy is high for a large crop of paper birch and low for a small crop.

Since germinative energy gives some idea of how rapidly germination progresses, it is perhaps better than germinative capacity as a standard for comparing years and as a practical measure of the average viability of a seed crop. Rapidity of germination can have an important bearing upon seedling survival. Seeds with high germinative energy will germinate early and thus produce seedlings that will have a maximum length of time to become established before summer drought and high temperatures increase the risk of mortality.

Seed Weight

Germination appears to be related to seed weight as well as abundance of seed. Paper birch seed from the Massachusetts stand was separated into four broad weight classes. From each of these classes, five samples of 20 cc. each were taken, accurately weighed, and tested for germinative capacity. The results showed that the seed in the heaviest weight class had an appreciably greater germinative capacity than the other weight classes:

Average weight per 20 cc. of seeds (mg.)	*Germinative capacity (percent)*
3.901	72
3.097	49
2.430	50
2.298	46

The investigation in Maine showed similar results. Here, however, the average weight per seed was determined for each of 3 years and was related to the germinative capacity for the same year:

Year	*Average weight per seed (mg.)*	*Germinative capacity (percent)*
1958	0.30	13
1959	.29	24
1960	.37	77

.vever, seed weight is influenced not only by size but also by soundness (the percentage of seeds that are fully developed). Since the seeds used in the tests mentioned above were not sorted on the basis of soundness before testing, the better germination of the heavier seeds might be a valid relationship or simply a reflection of a higher proportion of sound seed.

Conclusions

The results on seed production, dispersal, and germination reported here provide only limited knowledge of paper birch seed-crop characteristics. Need exists for more detailed information if we are to utilize the seeding habits of paper birch to best advantage. Yet there is a practical implication in the data we already have: to encourage the successful establishment of a new paper birch stand, regeneration cuts should be made during a good seed year, and seedbed preparation treatments should be completed by the end of summer.

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FOREST SERVICE
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DEPARTMENT OF AGRICULTURE

by Frank E. Cunningham
and Richard J. Peterson

AIR-LAYERING SUGAR MAPLE

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AIR-LAYERING SUGAR MAPLE

A Problem of Propagation

IN RESEARCH to improve sugar maple trees, a major difficulty has been to produce clonal material for testing. Even though several workers have successfully rooted cuttings of sugar maple (Snow 1941; Dunn and Townsend 1954; Enright 1958; Gabriel, Marvin, and Taylor 1961), few of the rooted cuttings have lived beyond the first winter. The problem of severe overwinter losses of rooted cuttings remains to be solved.

Recent studies on the Hopkins Memorial Experimental Forest at Williamstown, Massachusetts, have demonstrated that branches of sugar maple can be rooted by air-layering, and that branches so rooted can be overwintered and grown with moderate success — at least with enough success to provide an adequate stock for research purposes.

The purpose of our studies with sugar maple was to develop a method by which superior sugar producers could be vegetatively propagated and grown for use in studies designed to improve

sugar yields. Because high sugar producers will ordinarily be selected from trees of tapping size, our studies were conducted on relatively large roadside sugar maples (fig. 1). Branches on a couple of young sugar maples less than 2 inches d.b.h. were also treated.

Figure 1.—Air-layering a roadside sugar maple. All the work was done on branches that could be reached either from the ground or from a temporary platform on a truck.

Procedures

Air-layering is a method of propagation whereby roots are induced to form on branches still attached to the original tree. Many workers have used this method to propagate species that are difficult to propagate on their own roots by other vegetative methods (Mergen 1955, Mergen and Cutting 1958, Zak 1956, and Bonner 1963).

The air-layer is applied to a sugar maple branch in much the same way as for other woody species. A branch selected for treatment is first wounded by girdling at the point where roots are desired; then the wound is treated with a root-inducing hormone, covered with a moist medium, and wrapped with a waterproof material. After a few weeks, when roots have formed and grown through the surrounding medium the branch is severed below the roots and planted as one would plant a seedling.

The basic steps in applying an air-layer to a sugar maple branch (fig. 2) are as follows:

1. Select the Branch and the Position on it for Treatment

At the place where roots are desired, the branch should be strong enough to support the weight of the package that will result when treatment is completed. Branches 3/16 inch or larger in diameter at the point of treatment usually will withstand moderately high winds without breakage.

A branch should have made at least 4 inches of terminal growth the previous year to provide space for placing the package without covering newly formed leaves near the branch tip.

The treatment should be applied to a node marking the position of a previous terminal bud (fig. 2, A). Internodal positions do not respond as well.

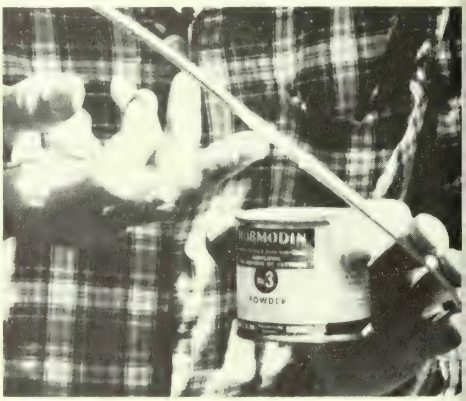
2. Girdle the Branch to Induce Rooting

Carefully remove the bark and all traces of cambium tissue from a 1-inch wide band around the branch at the point where

Figure 2. — Steps in air-layering a sugar maple branch.

A. Select position for girdle.

B. Make the girdle.



C. Apply rooting compound.

D. Cover with moist sphagnum.

E. Tie waterproof plastic wrapper.

roots are desired (fig. 2, B). Avoid cutting into the wood when making the girdle. Cuts in the wood weaken the stem mechanically and may result in breakage.

3. Apply Rooting Compound

To stimulate root formation, apply a root-inducing hormone to the surface of the girdled area. An 0.8-percent mixture of indolebutyric acid in talc (Hormodin No. 3) has consistently given good rooting results in our work.

Moisten the surface of the girdled area to ensure adherence of the powder. The hormone can be applied easily either by dusting or simply by dipping a finger into the powder and then rubbing it over the girdled surface (fig. 2, C).

4. Place Moist Rooting Medium around the Treated Area

Sphagnum moss, thoroughly soaked in water, makes an excellent rooting medium. It holds moisture well, can be readily shaped around a branch and, because of its fibrous nature, can easily be held in the desired shape and position until a wrapper can be tied around it.

When applying the sphagnum, scoop up a liberal handful from the container, squeeze it as dry as possible, then separate it into two equal portions and place them so as to completely cover the girdle (fig. 2, D). Avoid twisting or turning the sphagnum around the branch, as this would wipe the rooting hormone from the treated surface.

5. Place the Wrapper and Tie it in Position

To hold the rooting medium in position and to retain the moisture needed for root formation, wrap a cover of moisture-proof material around the medium and tie it securely at each end (fig. 2, E). In our work clear polyethylene plastic, in sheets 7 x 9 inches, have proved satisfactory for this purpose. Once the wrapper is in place, no further steps are necessary until roots can be seen growing out of the medium, (fig. 3).

Figure 3. — Developing roots on an air-layered sugar maple branch.

Figure 4.—Roots forming in air-layers in young sugar maple stump sprouts.

Factors That May Affect Rooting Response

So far, only the mechanics of applying an air-layer to a sugar maple branch have been considered; little has been said about factors that may affect rooting response. The Williamstown studies provided useful information about a number of these factors, the highlights of which are as follows:

Time of Treatment

Best rooting resulted when treatments were applied at about the time the first flush of terminal growth had slowed down. In the Williamstown area, this usually occurs between late May and mid-June. Few roots, if any, developed when treatments were applied much before or much after that early-summer period.

Size or Age of Tree

In our work, size or age of tree was not a factor of great importance in rooting response. Although layers on 2-inch or smaller trees (fig. 4) appeared generally to develop somewhat more numerous and more vigorous roots, up to 91 percent of our layers on trees ranging from 13 to 36 inches d.b.h. were successfully rooted. This is in marked contrast to the effect of tree age on air-layering in shortleaf and loblolly pines: in those species layers on trees more than 10 years old are reported to be difficult to root (Zak 1956).

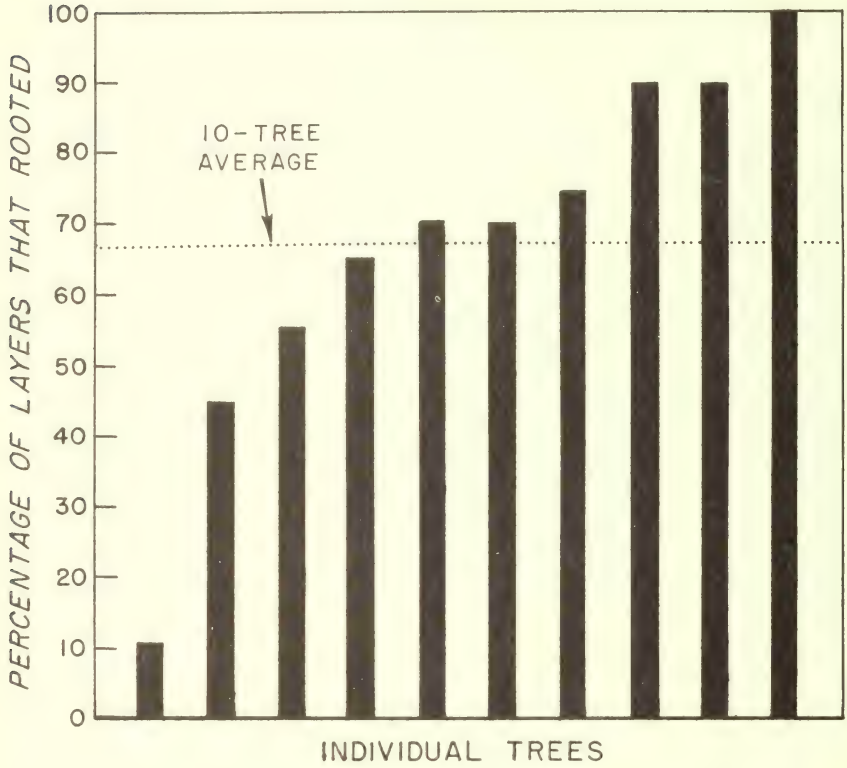
Influence of Crown Position of the Treated Branch

Within the lower third of the crown, where all our work on large trees was done, there was no evidence that crown position affected rooting response.

Variance of Individual Trees

We found that trees varied in rooting response. In 1959 an equal number of branches were treated identically on 10 roadside trees. The rooting by individual trees ranged from a low of 10

Figure 5. — Rooting responses of 10 roadside sugar maples on which equal numbers of branches were uniformly treated.



percent to a high of 100 percent. The general average for all 10 trees was 67 percent (fig. 5). The differences in rooting among trees were highly significant.

Type and Severity of Wounding

No rooting took place unless some form of complete girdle was made. Nicks, notches, and other wounds short of complete girdles resulted in calluses but no roots.

To determine whether severity of wounding influenced rooting response, girdles ¼, ½, and 1 inch wide were made on an equal number of branches on each of two trees. As width of girdle increased, so did the percentage of branches that rooted, as shown in the tabulation that follows:

Tree number	*1/4-inch girdle*	*1/2-inch girdle*	*1-inch girdle*
H-662	20	13	53
H-669	7	27	33
Average	13	20	43

The differences between means were significant. Girdles wider than 1 inch did not improve rooting. A stronger tendency of the narrower girdles to bridge over with callus tissue probably accounted for their poorer rooting.

Once the importance of girdle width was recognized, we achieved increasingly higher rooting percentages as we gained experience in applying the treatment. The following tabulation shows this trend:

Year	*Trees treated (No.)*	*Branches treated (No.)*	*Branches rooted (No.)*	*(Percent)*
1959	10	200	134	67
1961	4	405	298	74
1962	6	503	453	91

Treatment Position on the Branch

As stated earlier, rooting is less successful at internodal positions than at nodal ones.

As for different nodal positions, we worked on only two: (A) the base of the 1-year-old wood, and (B) the base of the 2-year-old wood (fig. 6). In one test, rooting response at these two positions was compared for an equal number of uniformly treated branches on each of six trees. Rooting at the younger position A averaged 88 percent, and at the older position B, 94 percent (table 1). This difference was not significant.

Although the final rooting response between the two positions did not differ significantly, rooting did proceed somewhat faster at the older position (fig. 7).

Figure 7 also shows that, in this series of treatments, root formation started during the fourth week after treatment and continued into the twelfth week. However, by the ninth week more than 90 percent of the rooting had taken place. This rate

of root formation is regarded as fairly typical for sugar maples in the Williamstown area.

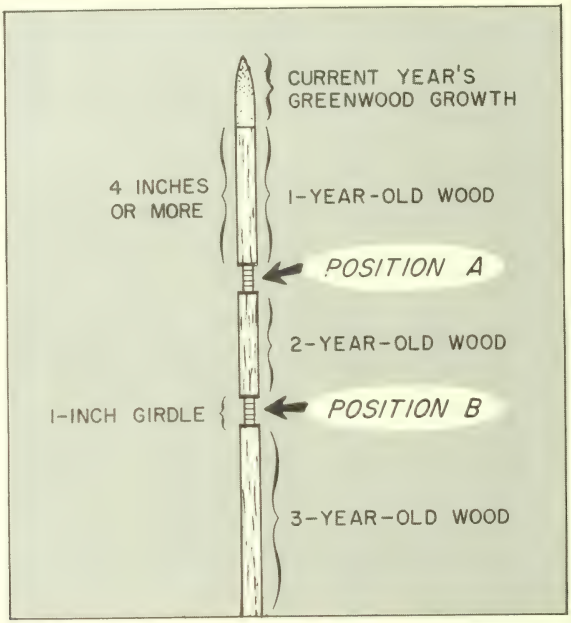


Figure 6. — Schematic drawing of treatment positions compared in this study.

Table 1. — Cumulative record of rooting at two treatment positions[1] on the branches of six trees

Weeks after treatment	Numbers of branches			Percent of total rooting		
	Position A	Position B	Total	Position A	Position B	Average
4	13	14	27	5.9	6.0	6.0
5	75	110	185	34.1	47.2	40.8
6	140	165	305	63.6	70.8	67.3
7	171	189	360	77.7	81.1	79.5
8	193	210	403	87.7	90.1	89.0
9	202	213	415	91.8	91.4	91.6
10	213	232	445	96.8	99.6	98.2
11	218	233	451	99.1	100.0	99.6
12	220	233	453	100.0	100.0	100.0
Total treated	251	252	503	—	—	—
Percent rooted	87.6	93.7	90.7	—	—	—

[1]Positions as shown in figure 6.

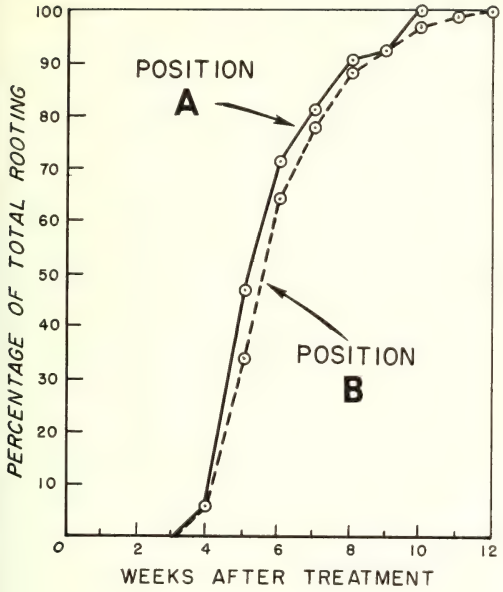


Figure 7. — Rate of root formation by treatment position.

Addition of Nutrients to the Rooting Medium

The addition of nutrients did not improve rooting response. In one test, branches treated with sphagnum moss soaked in plain tap water averaged 18 percent rooting as compared to 11 percent rooting for branches treated with sphagnum moss soaked in a dilute solution of Rapid-Gro, a liquid fertilizer.

Root-Inducing Hormones

On the basis of other research on other species, we assumed that root-inducing hormones would be effective on sugar maple, and adopted hormone treatment as standard procedure. We did not try any untreated controls and consequently do not have a direct measure of hormone efficacy on sugar maple. On slash pine, for example, Mergen (1955) reported 84.6 percent average rooting when branches were treated with 0.8-percent powdered indolebutyric acid (Hormodin No. 3), as compared with 50 percent rooting of controls. Quality and quantity of roots also were reported to be better on the treated branches.

Influence of Wrapping Material

There is evidence that some material may adversely affect rooting response. Clear polyethylene film was used recently in one experiment for wrapping air-layered branches on one tree and translucent vinyl plastic was used on branches of four other trees. For the polyethylene-wrapped branches, on-the-tree mortality was 5 percent; and for the vinyl-wrapped branches, the average mortality was 46 percent (24 to 77 percent by trees). Whether this difference in branch mortality was in fact due to the wrapping materials has not been definitely determined, but on this evidence it seems advisable not to use the vinyl plastic.

Such opaque materials as aluminum foil and black polyethylene film do not adversely affect rooting response but are inconvenient because wrappers must be opened to observe root development. Therefore clear polyethylene is recommended.

After-Rooting Procedures and Results

The earlier rooted branches are removed from the parent tree and started in soil on their own roots, the better the chances are for their over-winter survival.

Procedures

Starting around the fourth week after the air-layers have been applied, branches should be checked at weekly intervals; and those that show roots (fig. 3) should be cut from the parent tree and planted. Weekly checks should continue at least through the ninth week after treatment. By that time more than 90 percent of the root development probably will have taken place (fig. 7).

When planting an air-layer, remove the polyethylene wrapper just before planting. Planting should be deep enough to completely cover the ball of sphagnum and roots. During handling and when firming the soil around the ball, care must be taken not to damage the roots that are growing through or around the sphagnum. Water thoroughly after planting. We recommend

removing about 50 percent of the leaves at the time of planting to reduce water loss from transpiration.

In our work at Williamstown, we planted the air-layers 6 inches apart in rows 2 feet apart in nursery beds that had been prepared by plowing and harrowing. To protect the plants from excessive heat and transpiration stress during the establishment period, 50-percent shade and an intermittent fine spray of water were provided (fig. 8). The spray system was set to operate for 2 minutes every half-hour. One year we used an automatically controlled mist system instead of the spray system, and it served equally well.

Shade and spray were maintained until the end of August. Then the shade was removed and the spray was stopped to encourage hardening-off of the new growth.

To minimize compaction around the trees in our heavy soils, mulches of hardwood leaves and pine needles were liberally applied. This had the added benefit of both suppressing weeds and reducing evaporation of moisture from the soil surface.

Figure 8.—Nursery bed for starting rooted sugar maple air-layers under 50-percent shade and an intermittent fine spray of water. Sprinklers are mounted along the sides of the shade frame at mid-height.

Results

Survival of the air-layers after planting in the nursery beds was low. In one bed, where air-layers from four trees were planted in 1961, survival after 4 growing seasons ranged from 20 to 44 percent, and averaged 33 percent.

In a second bed, where air-layers from 6 trees were planted in 1962, survival after 3 years ranged from 11 percent to 48 percent and averaged 28 percent (table 2).

Table 2. — Survival of branches from six roadside trees that were rooted by air-layering and planted in 1962

Tree No.	Branches planted	Survival		
		Fall 1962	Fall 1963	Fall 1964
	No.	*Percent*	*Percent*	*Percent*
501	91	84	35	24
655	82	51	24	21
656	38	100	16	13
662	49	69	43	39
669	100	86	51	48
689	65	63	15	11
All trees	426	75	33	28

Individual trees varied considerably in survival. The most critical period was during the first growing season and over the first winter. Losses averaged 25 percent during the growing period and around 40 percent more during the first winter. After that, losses were relatively low. More work is needed to improve survival over this difficult first year.

Discussion

In comparison with rooting of cuttings, air-layering has certain advantages that recommend its use for vegetative propagation of sugar maple. The principal advantages are:

1. Fewer and less-elaborate facilities are required. To propagate by cuttings, special rooting beds equipped with precision controls for light and moisture (intermittent misting) are essential. Subsequent handling of the cuttings requires greenhouse, cold-room, or cold-frame facilities. For air-layering, no special facilities are needed until the rooted branches are cut from the parent tree; and then the only facilities needed are a simple shelter, to reduce insolation and transpiration stress, and an automatic sprinkling device.

2. Through the crucial first year, new plants from air-layers are generally in better condition to survive and grow than plants that originate from cuttings. This is because the roots on air-layers are formed while the branch is still attached to the parent tree and presumably drawing some nutrients from it. Cuttings, on the other hand, develop their roots almost entirely at the expense of previously stored carbohydrates and other food substances. In the process, most or all these food reserves are used up, and before they can be adequately replenished to carry the plant through the winter and support new growth the next spring, dormancy often sets in. Consequently, rooted cuttings go into the winter in a weak condition and few of them are able to break dormancy in the spring.

The chief disadvantages of air-layers are: (1) they involve more hand work per plant and hence would be less practical than cuttings for propagating in large numbers; and (2) after root formation in air-layers gets under way, the branches must be inspected weekly and those that have reached the planting stage must be removed.

Our survival results with air-layers (table 2), although considerably better than is usually achieved with cuttings, still fell far short of complete success. Further research on establishment and over-wintering of the air-layers will have to be done if survivals are to be substantially improved. At the present levels

of success, air-layering is a feasible and useful technique of vegetative propagation for special purposes, such as tree-improvement studies, but not for mass production. And even for limited use in research operations, further studies on ways to increase survival would be well justified.

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ORGANISM INTERACTIONS in Decay and Discoloration in Beech, Birch, and Maple

by Alex L. Shigo

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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
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Look to the Living Tree

HYMENOMYCETOUS FUNGI are the principal organisms that have been considered in past research on wood decay (Boyce 1961). Indeed few other organisms, except some of the Xylariaceae (Merrill *et al* 1965) and a few non-hymenomycetes (Savory 1954; Duncan 1960), produce enzymes capable of digesting wood. The existing information is mainly about decay by fungi of sterilized wood blocks in the laboratory.

But very little information is available about decay processes in living trees. What is known concerns mainly the final stages. Studies typically have dealt with cull following fire injuries (Toole 1959; Hepting 1935), logging wounds (Wright and Isaac 1956; Hesterberg 1957), pruning wounds (Roth 1948; Skilling 1958), and wounds caused by thinning of sprouts (Roth 1956).

Even less attention has been given to discolorations in living trees. Although many reports mention discoloration in living trees

(Nordin 1954; Hepting *et al* 1949), further research was not conducted. Discolorations have been primarily the research responsibility of the products pathologists (Scheffer and Lindgren 1940). Yet anyone who has ever cultured organisms from decayed areas in living trees has encountered many bacteria and non-hymenomycetous fungi along with hymenomycetes. Recognition of the possible importance of other wood-inhabiting organisms is increasing (Etheridge 1957; Good and Nelson 1962; Shigo 1963).

More emphasis needs to be given to the earlier stages of the decay and discoloration processes as they occur in living trees. Attempts have been made to determine the growth rate of hymenomycetes in living trees (Hirt 1949; Silverborg 1959). In these studies, only those fungi used as inoculum were considered in the results. If other organisms are involved, what are they and what role do they play in the discoloration and decay process?

Our studies indicate that interactions of many organisms besides hymenomycetes are involved in these processes. The purpose of this paper is to point out some of these interactions and to illustrate that bacteria, non-hymenomycetes, and hymenomycetes are all important in the processes that lead to decay and discoloration in beech, birch, and maple. Data from several studies are summarized.

Materials and Methods

From 1959 to 1964 investigations were conducted in New Hampshire of decay and discoloration in more than 1,000 northern hardwood trees: American beech *(Fagus grandifolia* Ehrh.); yellow birch *(Betula alleghaniensis* Britt.); paper birch *(B. papyrifera* Marsh.); sugar maple *(Acer saccharum* Marsh.); and red maple *(A. rubrum* L.). Most of the trees were more than 6 inches d.b.h., and all bore obvious infection courts, including branch stubs, stem stubs, parent stumps of sprouts, cracks, and wounds caused by logging, fire, squirrels, insects, and sapsuckers.

The trees were studied carefully both before they were cut, and later during and after dissection. The larger trees were dissected

longitudinally with a one-man chainsaw (fig. 1). More than 70,000 isolations for microorganisms were made from healthy and diseased tissues on a 2% agar medium consisting of 10 g malt extract and 2 g yeast extract/liter.

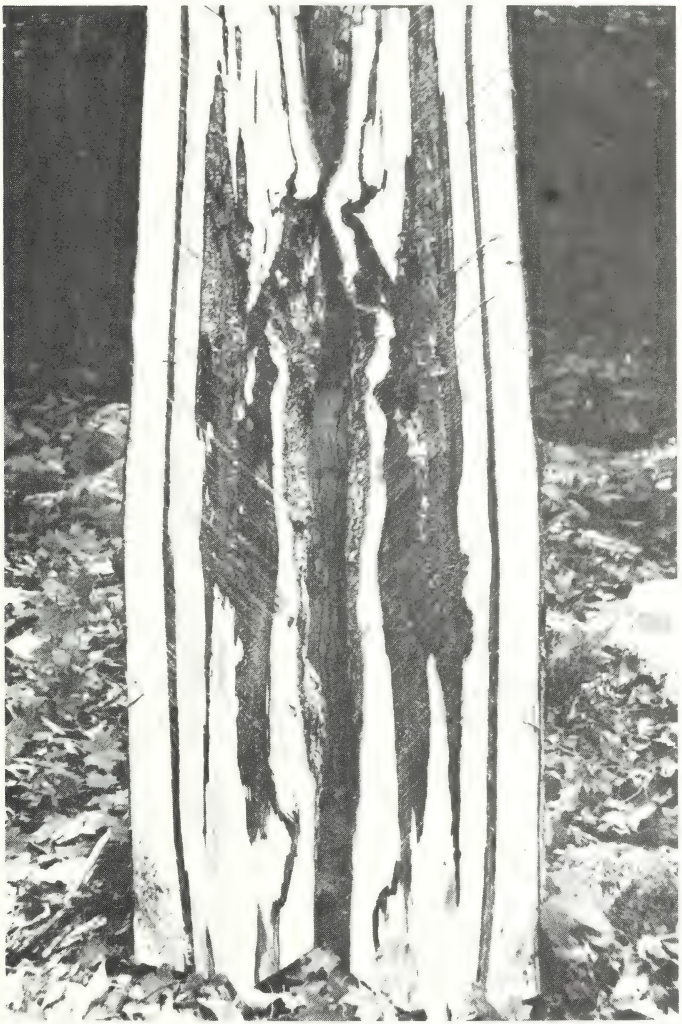

Figure 1. — Dissection of a red maple showing a column of dark decay, which yielded **F. connatus,** advancing through a column of light decay that yielded **F. igniarius,** which was surrounded by moist, dark discolored tissues that yielded bacteria and non-hymenomycetes.

Results

Data showing the associations of bacteria, non-hymenomycetes, and hymenomycetes in the decay and discoloration processes in living trees are presented in tables 1 to 8. These tables also indicate the relative frequency with which organisms were cultured from different types of infection courts.

Table 1 shows the numbers of squirrel wounds that yielded organisms. The squirrels wounded the trees from February to April during sapflow. The surfaces of the fresh wounds were colonized by many organisms. Yeasts were associated only with fresh wounds having moist surface tissues, while *Hypoxylon* spp. and *Phialophora* spp. were cultured only from older wounds with discolored tissues. These discolorations varied from green-black to bright green. Bacteria were cultured frequently from all the wounds.

Branch stubs were the principal infection courts on sprouts of *A. rubrum* (table 2). Non-hymenomycetes were associated more frequently with the pith and surrounding tissues in young stems of *A. rubrum* than with *A. saccharum* (table 3). Non-hymenomycetes also were the principal organisms cultured from *A. rubrum* sprouts over 10 years old (table 4). The principal non-hymeno-

Table 1. — Number of squirrel-caused wounds that yielded organisms

Organisms	*Acer saccharum*		*Acer rubrum*	
	Wounds less than 4 months old	Wounds over 1 year old	Wounds less than 4 months old	Wounds over 1 year old
Bacteria	29	20	20	7
Yeasts	20	0	15	0
Verticillium sp.	13	1	2	1
Cephalosporium sp.	15	6	2	2
Cladosporium sp.	5	1	1	0
Fusarium sp.	11	1	4	0
Hypoxylon spp.	0	4	0	3
Phialophora spp.	0	14	0	8
Wounds sampled	30	20	20	9

Table 2. — Principal infection courts on 261 sprouts of *A. rubrum*

Infection court	Number of sprouts	Percentage of sprouts
Branch stubs	126	48
Stump wounds	53	20
Branch stubs and stump wounds	47	18
Mechanical wounds	10	4
Sprouts clear to 8 feet above ground	25	10

Table 3. — Sprouts of *Acer* spp. approximately 1 inch in diameter and less than 15 years old that yielded organisms from the pith and surrounding tissues associated with small branch stubs

Organism	*A. rubrum*		*A. saccharum*	
	No.	%	No.	%
Bacteria	19	45	45	47
Non-hymenomycetes:	42	100	30	32
Cytospora decipiens	28	67	0	0
Phialophora spp.	17	41	16	17
Hypoxylon spp.	10	24	2	2
Trichocladium canadense	4	10	0	0
Hymenomycetes	4	10	9	9
No organisms isolated	0	0	42	44
Total, isolations	420	—	950	—
Total, sprouts sampled	42	—	95	—

mycetes cultured from discolored tissues associated with all types of infection courts on all species of northern hardwoods were *Phialophora* spp., especially *P. melinii* (Nannfeldt) Conant; *Trichocladium canadense* Hughes, and *Hypoxylon* spp., especially *H. rubiginosum* Per. ex Fries (tables 3, 4, 5, and 6). *Cytospora decipiens* Sacc. was cultured frequently, but only from discolorations in *A. rubrum* (tables 3, 4, and 5). *C. decipiens* was cultured frequently from the central column of discoloration in mature, vigorous trees with little decay. Tissues that yielded these fungi usually were red-brown to tan *(Hypoxylon* spp.), tan to green-black *(Phialophora* spp.), tan to red-brown *(T. canadense)*, and pink to pink-brown *(C. decipiens)*.

Table 4.—Red maple sprouts from 210 sampled that yielded organisms. The sprouts ranged from 10 to 75 years old

Organism	Number	Percentage
1. Bacteria	107	51
2. Non-hymenomycetes	183	87
3. *Cytospora decipiens*	85	40
4. *Phialophora* spp.	90	43
5. *Hypoxylon* spp.	52	25
6. *Trichocladium canadense*	52	25
7. Hymenomycetes	82	39
1 & 2	101	48
1 & 3	39	19
1 & 4	57	27
1 & 5	24	11
1 & 6	30	14
1 & 3 & 4	18	9
1 & 3 & 4 & 5	5	2
1 & 7	36	17
1 & 3 & 7	12	6
1 & 4 & 7	16	8

Table 5. — Numbers of trees wounded during logging that yielded organisms. The wounds ranged from 2 to 60 years old

Organism	Species and total number of trees sampled				
	Beech 82	Sugar maple 48	Red maple 29	Paper birch 46	Yellow birch 116
1. Bacteria	53	33	23	40	97
2. Non-hymenomycetes	72	45	29	41	115
3. *Phialophora* spp.	52	29	21	27	68
4. *Trichocladium canadense*	38	12	13	32	77
5. *Hypoxylon* spp.	34	13	9	7	33
6. *Nectria* spp.	12	8	5	5	17
7. *Coryne sarcoides*	4	2	1	2	7
8. *Graphium* sp.	3	2	1	2	7
9. *Cytospora decipiens*	0	0	6	0	0
10. Hymenomycetes	62	32	20	32	98
1 & 3	34	21	19	22	70
1 & 4	27	9	11	26	63
1 & 3 & 4	17	6	8	15	39
1 & 5	17	6	7	3	23
1 & 3 & 5	13	3	6	2	15
1 & 10	46	21	18	30	87
1 & 2	51	29	23	35	95
1 & 2 & 10	45	20	18	28	86

Table 6.—Frequency of organisms cultured from discolored tissues that surrounded decay columns caused by 4 hymenomycetes in 140 trees

Organism	Hymenomycetes			
	Fomes igniarius (All northern hardwoods)	*Polyporus glomeratus (Acer rubrum)*	*Poria obliqua (Betula* spp.)	*Pholiota squarrosa-adiposa (Betula* spp.)
NO. TREES THAT YIELDED HYMENOMYCETES				
Hymenomycetes	66	21	25	28
NO. TREES THAT YIELDED OTHER ORGANISMS				
Bacteria	63	21	24	27
Non-hymenomycetes:	56	20	22	26
Phialophora spp.	15	11	13	19
Trichocladium canadense	22	14	11	20
Hypoxylon spp.	25	10	3	4

The principal bacteria cultured were gram negative, motile, short rods that produced an abundance of slime. Several of these bacteria were identified tentatively as species in the genus *Pseudomonas*. Bacteria were cultured from tissues ranging in color from light yellow to dark tan.

The organisms associated with branch stubs, except *Hypoxylon* spp., first infected the pith and surrounding tissues. Microscopic examination of these tissues revealed phialophores producing spores, and bacteria (fig. 2). Tissues infected by bacteria and *Phialophora* spp. and *T. canadense* were darker and more moist than healthy tissues (fig. 1). Tissues infected by *C. decipiens* were bleached at first and later turned pink. Bacteria were associated intimately with all these fungi in the living trees, and wood chips used for isolations often yielded both bacteria and non-hymenomycetes (fig. 3).

Most isolations from discolored tissues associated with infection courts less than 5 years old yielded organisms. Histological examination of discolored tissues from living trees revealed hyphae in cells that were producing dark substances (fig. 4), especially ray cells. Usually discolored tissues not yielding organisms were those located nearest to healthy tissues.

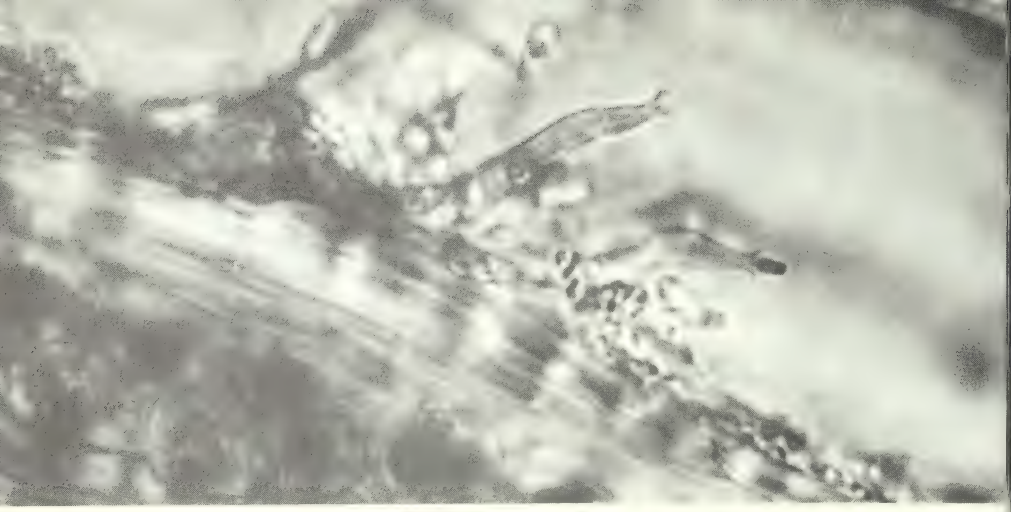

Figure 2. — Phialophores of **Phialophora** sp. producing spores in a vessel in discolored tissues from a living red maple.

Figure 3. — Bacteria and **T. canadense** were associated intimately in discolored tissues in living trees, and they grew well together in culture.

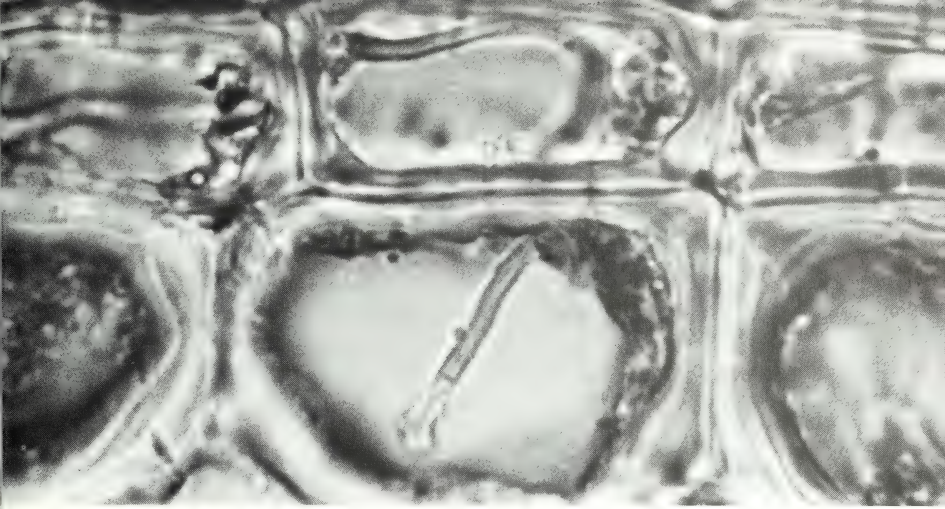

Figure 4. — Hyphae of a fungus growing through ray cells that were producing dark substances.

The rate of development of discolorations associated with a variety of infection courts on different trees varied greatly. Some large 13-year-old logging wounds on red maple trees over 10 in. d.b.h. had very little discoloration associated with them (fig. 5). In some cases, where *Nectria galligena* Bres. had infected the wounds, the discolored tissues beneath the wound surface were hard and dry. Also, some logging wounds not infected by *N. galligena* had hard, dry wound surfaces with very little associated discoloration (fig. 6). On the other hand, discoloration developed rapidly in some trees, and especially in association with branch stubs. Discolored streaks advancing from dead branch stubs often coalesced. Mature trees bearing few small infection courts contained light-colored wood from the cambium to the pith (figs. 5 and 6).

Discolored tissues formed only after an infection court was created. And — most important — wood tissues formed after the infection court was created were seldom infected. Therefore, the greatest diameter attained by the discolored column usually was the diameter of the tree when infection courts were created.

All degrees of discoloration from none to total involvement of those tissues present at the time of wounding were observed. Ob-

Figure 5. — Dissection of a red maple that had 2 large 13-year-old wounds. Very little discoloration was associated with the wounds. Perithecia of **N. galligena** were on the wound callus. There were few other defects in the tree, and the wood was clear from the cambium to the pith.

Figure 6.—Very little discoloration was associated with the hard, dry wound of this sugar maple. The branch stubs were well healed and the dark central discoloration was small.

servations and the results of statistical analyses indicated that the extent of the development depended on many factors, especially time and organisms. In the laboratory, discolorations similar to those in living trees formed in unautoclaved freshly cut stem sections inoculated with the principal non-hymenomycetes. In contrast, the controls remained clear.

Hypoxylon spp. usually were the first fungi to cause decay. These fungi were cultured frequently from a red and white mottled decay and discoloration associated with infection courts usually less than 8 years old and their stromata formed on logging wounds and branch stubs within this time. *Stereum complicatum* (Fr.) Fr. and *Polyporus versicolor* L. ex Fr. were usually the first hymenomycetes to infect logging wounds, and their sporophores were often found beside stromata of *Hypoxylon* spp. on the wounds. Stromata also occurred on wounds that bore sporo-

phores of fungi associated with more advanced decay, especially *Fomes igniarius* L. (Gill.) and *F. applanatus* (Pers. ex Wallr.) Gill.

The hymenomycetes invaded only discolored tissues already inhabited by other organisms, especially bacteria and non-hymenomycetes (tables 3, 4, and 5). The radial extent of the decay column usually was limited to this previously-formed column of discoloration (fig. 2). While the hymenomycetes were actively causing decay, the decay column was surrounded by discolored tissues that yielded either bacteria, non-hymenomycetes, or both (tables 3, 4, 5, and 6). After hymenomycetes had completely digested the discolored tissues, the walls of the hollowed column became hard and dry and yielded none of the organisms cited above. The diameters of such hollowed columns corresponded to the diameters of the discolored columns, which, in turn, corresponded to the diameters of the trees when the infection courts were created.

Exceptions to the pattern of decay and discoloration given above were encountered, especially if wounds were infected by *Poria obliqua* (Pers.) Bres. and *Polyporus glomeratus* Peck. These organisms infected the new tissues that formed around the infection courts. But, even when this occurred, the decay still was surrounded by moist discolored tissues that had a high pH, and yielded bacteria and non-hymenomycetes (table 6).

Often several hymenomycetes were cultured from the same decay column. In one tree, for example, a decay column caused by *Fomes connatus* (Weinm.) Gill. developed within the decay column caused by *F. igniarius,* which was surrounded by discolored tissues that yielded bacteria and non-hymenomycetes (fig. 1). Swollen knots formed by *P. glomeratus* occasionally bore sporophores of *F. igniarius.* Sporophores of several hymenomycetes on the same wound were common.

Organisms, especially bacteria, were cultured occasionally from the non-discolored tissues contiguous to discolorations (table 7) and from non-discolored tissues in other portions of the bole (table 8).

In culture, bacteria and non-hymenomycetes grew well together

Table 7. — Isolations that yielded bacteria from non-discolored tissues contiguous to discolorations in 27 trees

Distance in 1/16-inch units from discolored tissues that isolations were made	*Acer rubrum*		*Fagus grandifolia*		*Betula alleghaniensis*	
	Isolations made	Isolations yielding bacteria	Isolations made	Isolations yielding bacteria	Isolations made	Isolations yielding bacteria
	No.	*No.*	*No.*	*No.*	*No.*	*No.*
1	63	18	16	2	14	2
2	56	12	27	2	17	4
3	29	3	15	1	22	2
4	20	5	5	1	25	6
5	8	0	5	0	13	1
6	4	1	5	0	12	1

Table 8. — Organisms cultured from non-discolored wood

Tree	Isolations	Isolations that yielded bacteria	Isolations that yielded non-hymenomycetes
	No.	*No.*	*No.*
Fagus grandifolia	54	13	2
Acer rubrum	60	4	18
Acer saccharum	60	10	1
Betula alleghaniensis	48	1	0
Betula papyrifera	48	2	0

(fig. 7), but bacteria sometimes inhibited growth of hymenomycetes (fig. 8). *Fomes igniarius* and *P. obliqua* were not inhibited by *P. melinii* until the fungi made contact with each other. Bacteria isolated from the discolored tissues surrounding the decay caused by *F. igniarius* arrested growth of *F. igniarius* in culture even when the organisms were not growing close to each other (fig. 8). When *F. igniarius* grew alone in culture no pigment formed in the agar; but when it grew near bacteria, the agar and mycelium became dark. The bacteria isolated frequently from the discolored tissues surrounding *P. obliqua* had little effect on

Figure 7. — Bacteria and **C. decipiens** grew well together in culture. These organisms were cultured from the same tissues.

Figure 8.—Bacteria inhibited the growth of **F. igniarius** in culture. The bacterium was cultured from discolored tissues that bordered decay that yielded this fungus.

growth of the fungus. One of the most aggressive organisms in culture was *C. decipiens.* It grew well with the principal bacteria (fig. 7), and inhibited growth of many non-hymenomycetes and hymenomycetes.

Pigmentation, growth, and pH of the medium of *C. decipiens* and *P. melinii* were affected by the concentration of certain microelements in the medium (table 9). These fungi were white and the filtrate was clear in a liquid medium consisting of 5 g glucose and 1 g yeast extract/liter. But when minute amounts of manganese or calcium were added to this medium, *C. decipiens* produced a deep red pigment and *P. melinii* produced a black to green-black pigment.

Table 9. — Growth, filtrate pH, and pigmentation of *Cytospora decipiens* and *Phialophora melinii* in two liquid media: 5 g glucose and 1 g yeast extract/liter (5-1) and 5-1 plus 1 part per 100 million of manganese (5-1+Mn)[1] [2]

Days of growth when harvested	*Cytospora decipiens:* media				*Phialophora melinii:* media			
	5-1		5-1+Mn		5-1		5-1+Mn	
	mg dry wt.	*pH*	*mg dry wt.*	*pH*	*mg dry wt.*	*pH*	*mg dry wt.*	*pH*
3	4	5.4	4	5.3	5	4.9	5	4.9
4	11	4.9	12	4.8	12	4.2	12	4.2
5	20	4.3	[4]27	4.3	14	4.0	[7]16	3.9
6	23	4.1	34	4.0	15	3.8	20	3.7
7	24	4.1	[5]38	4.1	17	3.8	[8]23	3.7
10	[3]30	4.2	37	3.8	18	3.7	28	3.8
12	30	4.1	40	3.7	[6]21	3.7	36	3.9
14	35	4.0	40	3.7	25	3.7	39	4.1
17	35	4.0	39	4.4	27	3.9	47	6.1
20	35	4.2	38	5.1	38	5.0	44	6.8
24	35	5.2	40	5.5	44	6.8	40	7.5
26	35	5.8	39	5.8	41	6.6	39	7.1
28	34	5.4	37	5.9	37	7.1	38	7.4

[1] 3 flasks of each at each harvest.
[2] 5.6 initial pH of media.
[3] Filtrate clear, mycelium gray-green.
[4] Filtrate light red.
[5] Filtrate red.
[6] Mycelium and filtrate cream.
[7] Mycelium gray, filtrate clear.
[8] Mycelium green-black.

P. melinii readily utilized 7 different nitrogen sources, including potassium nitrate, but only yeast extract satisfied the growth requirements of *C. decipiens* (table 10). For *C. decipiens* the optimum pH was 3.5 with yeast extract as the nitrogen source, while *P. melinii* grew well with glutamic acid at a pH of 7.8 and with

Table 10. — Growth and pH of *Cytospora decipiens* and *Phialophora melinii* in media[1] having 7 different sources of nitrogen

Nitrogen source	*C. decipiens*			*P. melinii*		
	Greatest mycelial dry wt. attained	pH[2]	Days	Greatest mycelial dry wt. attained	pH	D
Asparagine	36	6.1	26	51	6.0	
Glutamic acid	34	4.8	26	59	7.8	
Glycine	42	6.0	21	34	7.2	
Yeast extract	85	3.5	7	62	4.5	
Potassium nitrate	1	4.8	33	33	7.1	
Ammonium tartrate	36	5.5	36	54	3.0	
Ammonium nitrate	31	2.7	26	59	2.6	
No added nitrogen	0.8	4.3	18	0.5	6.0	

[1] Basal medium, per liter: glucose, 5 g; KH_2PO_4, 1 g; $MgSO_4 \cdot 7H_2O$, 0.5 g; Fe, 0.1 mg; Zn, 0.1 mg; Mn, 0.05 mg; Ca, 10 Mg; Thiamine, 100 ug; Biotin, 5 ug; nitrogen, equivalent to that in 1 g of Asparagine.

[2] Initial pH of all media approximately 6.

ammonium nitrate at a pH of 2.6. The growth of *C. decipiens* was jelly-like in all media except where yeast extract was used, and there was little to no pigmentation in all media. *P. melinii* formed a firm pad in all media and the mycelium was dark, especially in the medium with potassium nitrate.

Conclusion and Discussion

The wood-living bark interface is disrupted upon creation of an infection court. Mechanical wounds to stems expose wood. When branches are broken, the pith is exposed also. Certain physiological processes begin in cells following injury prior to invasion by organisms. In many plants the cellular phenols are oxidized and polymerized subsequently to polyphenols. Some of these materials are thought to cause a protective effect (Frank 1895; Zycha 1948; Jorgenson 1962). Büsgen and Münch (1931) considered this when they discussed "protective heartwood." The protective zone that formed after fire wounds may be another example (Hepting and Blaisdell 1936). Changes in air and moisture that result from wounds probably initiate the production of polyphenols (Frey-Wyssling and Bossard 1959).

It is difficult to state how far the protective processes ensue before micro-organisms become involved. The time between initiation of protective processes and arrival at infection courts of organisms capable first of competing with other organisms and second of infecting living cells may be the principal factor affecting the distructive processes. Time of year when infection courts are created may be an important factor affecting production of the protective substances. The healing of pruning wounds on oak (Roth 1948) and mechanical wounds on several hardwood species (Marshall 1931) was affected by season of year.

The fact that some mature trees heal their branch and mechanical wounds with very little associated decay and discoloration suggests that the protective barriers may be effective sometimes. On the other hand, the fact that many mature trees have extensive columns of decay and discoloration associated with infection courts suggests that the protective barriers, if formed, are not always effective. Variations in the amount of internal defect between these two extremes suggest that many different pathways may exist that lead to different types and amounts of defect.

Isolations from recent wounds yielded bacteria and many species of non-hymenomycetes. As the ages of the wounds increased, the

succession of organisms was evident. A struggle for survival on the infection courts probably occurred. Some of the organisms involved are not parasitic on trees but on other fungi. For example, on beech the parasite *Nectria coccinea* var. *faginata* Lohm. Wats. & Ayers. is attacked by the mycoparasite *Gonatorrhodiella highlei* Smith (Ayers 1941; Blyth 1949; Shigo 1964).

Many large logging wounds had very little defect related to them. *Nectria galligena* was associated with some of these. The wood behind most *Nectria* cankers is sound and is fairly resistant to decay (Brandt 1964). The fungus requires a special type of infection court (Lortie 1964); and, once it infects, apparently few other organisms can do likewise. The fungus is very pathogenic but not aggressive. This condition has been discussed by Barnett (1959).

Bacteria were cultured frequently from all ages and types of wounds. High moisture and pH were characteristic of the discolored tissues that yielded these organisms. Such zones are termed wetwood (Hartley *et al.* 1961). Duncan (1960) demonstrated that hymenomycetes grew poorly, and soft-rot fungi grew very well under such conditions. In our studies, bacteria were associated intimately with the principal non-hymenomycetes that were the first to infect the tree. Possibly hymenomycetes cannot invade until the high moisture and pH of the wood are both lowered. Hymenomycetes did not always infect discolored tissues; continued high moisture and pH may be the reason.

The principal bacteria cultured were motile, suggesting that their movement through the tissues was possible. This may account for the few isolations that yielded bacteria from non-discolored tissues contiguous to discolored tissues. But this does not explain the presence of bacteria in non-discolored tissues in trees without discolorations. The bacteria may have entered through minute wounds that healed rapidly and were not detectable when the isolations were made. The wounds made by scale insects on beech may have accounted for some of these. Regardless of how they got there, some bacteria were present in non-discolored tissues. Therefore it is possible that inoculations into supposedly organism-free wood might actually place the inoculum in the presence of

bacteria. Also, the wound made for the inoculation may stimulate the activity of the bacteria.

The discolorations in northern hardwoods are caused by processes that are initiated by wounds (Shigo 1965). Organisms caused discoloration in unautoclaved stem sections in the laboratory. In living trees organisms are associated frequently with discolorations, and the circular central discolorations found commonly in northern hardwoods are not considered true heartwood (Shigo 1965). Because organisms are associated commonly with these tissues, it is incorrect to assume that organisms inoculated into such tissues are being placed into organism-free tissues or into true heartwood. Brandt[1] (unpublished) conducted experiments similar to those of Silverborg (1959) and Hirt (1949). But, although Brandt put but one fungus into supposedly organism-free tissues, at the time of harvest he cultured bacteria and non-hymenomycetes consistently from the discolored tissues surrounding the decay tissues.

Most non-hymenomycetes and bacteria grew well together in culture, but often these organisms inhibited growth of hymenomycetes. A similar association in living trees may be operating, which would explain why decay is limited by discoloration. Indeed, the exception to this, *P. obliqua,* infected newly formed tissues, and grew well with bacteria in culture. In culture, bacteria stimulated pigmentation by *F. igniarius.* The dark lines associated with *F. igniarius* in the living tree may result from a similar association.

Trees growing on different parent soils could contain different amounts of micro-elements in their wood. This was pointed out by Ellis (1959) for grand fir growing on the western and eastern slopes of the Cascades. The concentration of micro-elements in the medium affected growth and pigmentation of *P. melinii* and *C. decipiens.* Possibly trees growing on different parent soils could be affected differently by these fungi.

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[1] R. W. Brandt conducted these studies while a member of the Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture. Brandt is now Assistant Director of Forest Disease Research, U. S. Forest Service, Washington, D. C.

P. melinii was cultured from discolored tissues of all northern hardwoods, while *C. decipiens* was cultured only from discolored tissues of *A. rubrum*. The selectivity of *C. decipiens* may be due to its exacting requirements for certain nitrogen sources that are available only in *A. rubrum*, and particularly nitrogen sources in those tissues around the pith. *C. decipiens* inhibited the growth of many other organisms in culture. This may explain why it was cultured most frequently from trees with little decay caused by other fungi. The central pink discoloration that yielded *C. decipiens* was common in trees classed as vigorous.

In our studies bacteria and non-hymenomycetes invaded first. When hymenomycetes invaded later they always grew through the discolored tissues. These results indicate that bacteria, non-hymenomycetes, and hymenomycetes must all be considered in the processes that lead to cell destruction in living trees. Discoloration can exist without decay; but decay is always associated with discoloration. Therefore, to understand decay we must also understand discoloration.

Summary

Physiological and ecological studies were conducted in New Hampshire, U. S. A., on factors affecting decay and discoloration associated with logging wounds, branch stubs, and other infection courts in *Acer saccharum, A. rubrum, Betula alleghaniensis, B. papyrifera,* and *Fagus grandifolia.* More than 1,000 trees were examined. Each tree was studied immediately before felling, and after, when it was dissected longitudinally with a chainsaw.

The organisms selected for more intensive study were those cultured most frequently from more than 70,000 isolations: non-hymenomycetes, *Phialophora* spp., *Hypoxylon* spp., *Trichocladium canadense,* and *Cytospora decipiens;* hymenomycetes, *Poria obliqua, Polyporus glomeratus,* and *Fomes igniarius;* and bacteria, *Pseudomonas* spp.

Once wood tissues were exposed, a succession of events began that involved abiotic and biotic factors. Bacteria and non-hymenomycetes were associated frequently with discolorations, but all

discolored tissues did not yield organisms. However, some non-discolored tissues yielded organisms. Hymenomycetes invaded only discolored tissues. The rate and extent of decay and discoloration depended primarily on types of infection courts, time, and organisms. Decay and discoloration seldom affected wood tissues that formed after an infection court was created. A common exception to this was caused by *P. obliqua.* Discolorations initiated by wounds were not considered heartwood. Cultural studies indicated that bacteria stimulated pigmentation of some fungi. Bacteria inhibited growth of many hymenomycetes. Pigmentation of some fungi was greatly affected by the concentrations of manganese and calcium in the medium.

Results of these studies indicated that bacteria, non-hymenomycetes, and hymenomycetes must all be considered in the processes that lead to discoloration and decay in living trees.

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Silvics and silviculture of Virginia pine. By Richard H. Fenton and Adna R. Bond. U. S. Forest Serv. Res. Paper NE-27, 36 pp., illus. 1964.

Timber industry opportunities in selected areas of West Virginia. By Perry R. Hagenstein. U. S. Forest Serv. Res. Paper NE-28, 72 pp., illus. 1964.

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Germination of eastern white pine seed as influenced by stratification. By Raymond E. Graber. U. S. Forest Serv. Res. Paper NE-36, 9 pp., illus. 1965.

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The mensurational characteristics of eastern white pine. By Robert Marty. U. S. Forest Serv. Res. Paper NE-40, 73 pp. 1965.

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Air-layering sugar maple. By Frank E. Cunningham and Richard J. Peterson. U. S. Forest Serv. Res. Paper NE-42, 16 pp., illus. 1965.

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A selected and annotated BIBLIOGRAPHY *of* Eastern White Pine *(Pinus strobus* L.), *1890-1954*

compiled by
Robert W. Wilson, Jr. and Ashbel F. Hough

U. S. FOREST SERVICE RESEARCH PAPER NE-44
1966

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
RALPH W. MARQUIS, DIRECTOR

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IN both North America and Europe, the growth, management, and use of white pine *(Pinus strobus* L.) has long attracted intense interest; and a great mass of literature — some of it dating from the 17th Century — has been published about this valuable species.

No one has ever made a thorough compilation and organization of this great mass of literature about white pine, and much of the literature has been inaccessible to the forestry profession. Therefore it was felt that the reduction of this material to a more accessible and usable form would be extremely helpful to practicing foresters, research workers, lumbermen, teachers, students, and laymen interested in white pine.

This bibliography is an outgrowth of a literature review prepared by the senior author as part of a problem analysis for the

white pine region of New England and New York. The authors' objective was to make available — to the layman and professional alike — the results of observations and experiments with white pine that could contribute toward its culture and use. With this broad objective in mind, all known literature on the subject as well as illustrative material was examined and given consideration.

More than 3,000 references have been collected. Of these, 944 that were published between 1890 and 1954 are included in this bibliography. The year 1890 was selected for the starting date because the publications of Gifford Pinchot, Henry S. Graves, C. S. Sargent, V. M. Spalding, and B. E. Fernow during the 1890's marked the beginning of the modern era of scientific investigations into the properties of eastern white pine. The closing date, 1954, was the latest year for which a reasonably thorough literature search could be made at the time the bibliography was being prepared.

Selections were based primarily on the originality of the work or the ideas presented. However, it was necessary to modify our selections in several ways. First, the limitation of space prevented the inclusion of all the original material available. Second, some publications not notable for originality were included because they are comprehensive in scope or contain literature reviews that supplement this bibliography, or clearly present information on which action can be based. Third, references such as textbooks that are widely available but contain only scattered or incidental material on eastern white pine have been omitted. Finally, only published material is included because the cost of tracing unpublished material proved prohibitive in relation to its overall value.

The bulk of the references included deal directly with the silvics, phytosociology, silviculture, protection, and management of white pine. In addition, many of the significant publications in taxonomy, morphology, physiology, genetics, wood anatomy, wood technology, logging, manufacturing, end uses and marketing, and resource and economic statistics are included.

Each of the titles is annotated. In most, the important conclusions about white pine are given, together with the author's basis for these conclusions. In some cases the subject matter and scope

of the publication are described. The latter type of annotation was used mainly for comprehensive publications covering a number of subjects for information-type publications, and for some publications giving detailed and lengthy treatment to one subject not directly related to the culture or use of white pine.

The search for white-pine literature was made through a number of channels. The catalogs of these libraries were consulted: U. S. Department of Agriculture (including Forest Service and Departmental libraries), Yale University School of Forestry, Harvard Forest, New York State University College of Forestry at Syracuse University, and the Library of Congress. The indices to all volumes of Forestry Abstracts, Biological Abstracts, Journal of Forestry, Forestry Quarterly, Ecology, and Ecological Monographs were checked. The publication lists of the Canada Forestry Branch and the U. S. Forest Service were also checked.

Special mention must be made of the inclusion of two publications that appeared after completion of this bibliography. One (Hirt, 1959) is an exhaustive annotated bibliography of the fungus diseases of eastern white pine. The other (Horton and Bedell, 1960) not only contains an extensive bibliography but is the first monograph involving the ecology, silviculture, and management of eastern white pine to appear in many years. Both are of extraordinary value.

Many people gave encouragement or help in various ways. Glenn R. Allison and F. H. Eyre, of the U. S. Forest Service; T. T. Kozlowski, University of Wisconsin; D. M. Smith, Yale University; and J. W. Wright, Michigan State University, contributed lists of references they had collected. Adrian M. Gilbert, of the Forest Service, gave valuable assistance with translations of foreign articles. Their aid is gratefully acknowledged.

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FOREST POLICY : RESOURCE STATISTICS

Anonymous. 1934. **White pine *(Pinus strobus* Linnaeus).** Amer. Forests 40: 360-361, illus.

A botanical description of the species, its range, uses, sites and pests. Illustrations of form, needles, cones, and bark.

Adkin, B. W. 1916. **Weymouth pine in the Surrey Desert.** Quart. Jour. Forestry 10: 185-193.

A 6-acre, 70-year-old plantation on wet sandy soil in a heather barren in England yielded 4,000 cubic feet per acre in trees averaging 53 feet high and varying widely in diameters. Calculations show that the stand yielded 4% interest on the investment in land and planting. The land was good for little else.

Albert, A. 1914. **El pino blanco Americano, *Pinus strobus.*** Bol. Bosque, Pesca i Caza 2: 428-433, illus.

Reviews American species planted in Chile, and concludes that white pine should be planted only on the best sites. On other sites it is equalled or exceeded in growth by *P. excelsa,* which produces timber equally good.

Badoux, Henri. 1920-21. **Le pin Weymouth *(Pinus strobus)* en Suisse.** Jour. Forest. Suisse 71: 221-227; 72: 86-89; 131-135, 148-152, 165-173.

Known plantations of white pine in France and Switzerland are discussed in relation to sites, growth, and pests. Recommends that white pine be widely planted on public forests.

Badoux, H. 1929. **Le pin Weymouth en Suisse.** Sta. Fed. de Rech. Ann. 15 (1): 105-183.

Describes distribution of white pine in Switzerland and the experimental plots being used to study the species. Chapters on height and volume growth, site requirements, uses and prices of the wood, and enemies of the species. Although attacked by many diseases (especially blister rust) and insects, white pine is recommended for cultivation because of its rapid growth and fine quality.

Betts, H. S. 1954. **Eastern white pine.** U. S. Dept. Agr. Amer. Wood Ser. 8 pp., illus.

A brief account of the history, distribution, growth, supply, properties, and uses of eastern white pine as a timber tree.

Borchers (first name not given). 1952. **Folgerungen aus den bisherigen Anbauergebnissen mit fremdlandischen Holzarten im Gebiet des Landes Niedersachsen für die kunstige waldbauliche Planung.** Mitt. der Deut. Dendrol. Gesell. Jahrb. 1951-52 (57): 69-81.

Notes on various species, with an indication of the total area planted to each, and a few growth data. White pine, despite losses from blister rust, has done better than the native *Pinus sylvestris*.

Canada Forestry Branch. 1923. **White pine.** Canada Forestry Branch Tree Pamphlet 1, 8 pp., illus.

A description of white pine, including brief notes on its place in the lumber industry, quality, uses of the wood, habit and form of growth, natural reproduction, propagation, and planting.

Canada Lumberman. 1934-43. **(Annual white pine number.)** Canada Lumberman vols. 54-63.

The annual white pine issues of this lumber trade journal contain many brief articles and editorials on new uses and markets for white pine. Also included are articles on price and supply trends, annual cut, protection from blister rust, and occasional notes on management. In substance, the articles tell what is being done to promote the use of white pine and to perpetuate the industry.

Cary, Austin. 1923. **The future of New England forests.** Jour. Forestry 21: 15-24.

The author discusses the place and form of private enteprise in the forestry business and the over-riding importance of location, species, site, and growth rate in the future. Intensive management is appropriate for the white pine region of central New England, in the author's opinion, but extensive management will probably continue to be appropriate for northern New England.

Chapman, H. H., and William P. House. 1952. **Forest practice survey report.** Pulpwood Res. Center, 191 pp., illus. Gorham, N. H.

A survey of cutting practices in New England, New York, and Pennsylvania, together with discussion of the condition of the major forest types and recommendations for improvement of current practices. In the white pine type the recent cutting was reported to be poor, with only about 40% of the cuttings being of a nature to keep the land productive.

Collingwood, G. H., and Warren D. Brush. 1947. **White pine.** ***In*** **Knowing your trees.** ed. 3, pp. 8-9, illus. Washington, D. C.

A brief natural and economic history of white pine.

Cook, H. O. 1929. **A forest survey of Massachusetts.** Jour. Forestry 27: 518-522.

A survey of Massachusetts forests made between 1914 and 1929, showed that the total area of the State, 5.3 million acres, included 2.8 million acres of woodland and 400,000 acres of agricultural land reverting to woodland. Of the woodland, 10.6% was in white pine type and 11.3% was pine-hardwood.

Cope, J. A. 1932 **Northern white pine in the southern Appalachians.** Jour. Forestry 30: 821-828.

In the southern part of white pine's natural range, lumbering, fire, and insects have greatly reduced its distribution and it meets strong competition for abandoned fields from southern pine in some localities. Its excellent growth rate and little real danger from weevils or blister rust should make it an important species for forestry

Corhin, A. 1927. **Le pin Weymouth dans la foret communale d'Epinal (Vosges).** Bul. Trimest. Soc. Forest. Franche-Comte 17 (1): 19-22.

White pine planted 40-60 years ago on low, wet, peaty areas of the Vosges Mountains has grown tall and straight and the stands now have volumes of 200-400 cubic meters per hectare. The trees produce good crops of seed almost every year and reproduce themselves naturally. They appear to have attained maturity at about 60 years.

Cunningham, R. N., and others. 1950. **Forest resources of the Lake States region.** U. S. Dept. Agr. Forest Resource Rpt. 1, 57 pp.

Gives an inventory of the Lake States forests and the timber growth and drain on them. White pine, once extensive, occupied only 2% of the forest land. Of the 40 billion board feet of sawtimber in the Lake States, 2.4 billion was white pine. Total cordwood volume was 180 million cords, of which 4 million was white pine, 2.7 million red pine, and 7 million jack pine.

Dallimore, W., and A. Bruce Jackson. 1948. ***Pinus strobus* Linnaeus. White pine or Weymouth pine.** ***In*** **A Handbook of Coniferae, including Ginkoaceae,** pp. 551-554, illus.

Briefly gives synonymy, identification, distribution, size and habit, wood properties, uses, and silvical characteristics. Planting, growth, and protection of the species are discussed.

Delevoy, G. 1938. **Les resineux au champ d'essais de belle-etiole (Foret de Soignes).** Soc. Cent. Forest. Belgique Bul. 45: 283-295, illus.

White pine was among the exotic conifers established in small plantations between 1906 and 1915 in the Forest of Soignes, Belgium. Growth in height, diameter, basal area (at breast height, mid-height, and 7 cm. top), volume, and form coefficients are shown in tables and graphs with corresponding figures for *P. silvestris.* All the exotics surpassed the native pine in some or all respects.

Federal Reserve Bank of Boston. 1950. **Eastern white pine — Nature's gift to New England.** Fed. Reserve Bank Boston Mo. Rev. 32 (9): 1-2.

A popular history of white pine as a timber tree and a statement of its importance in the New England economy.

Fisher, Richard T. 1928. **Pine plantations and New England forestry.** Jour. Forestry 26: 790-793.

During the first quarter of the century, forestry in New England has meant primarily the planting of white pine. White pine should not be planted in pure stands because white pine growth drops fast at 50-60 years, red rot is frequent, and health, quality, and market value are all poor.

Giordano, Guglielmo. 1934. **Il pino strobo *(Pinus strobus* L.).** L'Alpe 21: 342-348, illus.

A brief note on the suitability of white pine for growth in Italy. Botanical characteristics, origin of the species, and its culture in central Europe and in Italy are discussed. The growth attained by some older plantations at several places in Italy is recorded and natural regeneration is discussed.

Grumbine, A. A. 1941. **Natural range does not limit white pine.** U. S. Forest Serv. Plant. Quart. 10 (1): 10-11.

White pine seedlings obtained from Michigan were planted in 1910 on the Ouachita national Forest in Arkansas. By 1940 the trees were producing cones, seeds, and seedlings. Mean annual growth was satisfactory, in spite of suppression during most of the 30-year period.

Guidaudeau, C. 1942. **Etude sur le pin Weymouth dans les Vosges.** Rev. des Eaux et Forets 80: 457-460, 507-511.

Pinus strobus was introduced into the Vosges about 1850 and was used principally from 1860 to 1869 for planting moist sites. It has grown well and produces abundant regeneration, but is seriously threatened by attacks of *Peridermium strobi*. Notes on the location and condition of white pine plantations in the region, and a special study of plantation growth and development in the Epinal Communal Forest.

Hatt, G. 1912. **Plantations de pin Weymouth dans les Terrains Marecageux.** Rev. des Eaux et Forets 51: 193-195.

An 8-acre plantation was planted in 1873 in a poor, open coppice stand on marshy ground near Epinal. In 1911 the stand, which bore seed annually, contained 150 trees per acre, 8 to 20 inches in diameter, and grew nearly 72 cubic feet per year for a total of 3,300 cubic feet. Average diameter was less than 12 inches. It is figured that the stand paid 5% interest on original costs and improved the site fourfold.

Heiberg, Svend O. 1953. **White pine research.** N. Y. Forester 10 (2): 1-7.

Since the beginning of forestry practice in the Northeast, white pine has been severely damaged by blister rust and the weevil. As a result the species has fallen into disrepute. But white pine is still a profitable and a highly desirable species to manage. The key to success is intensive management practice.

Horton, K. W., and G. H. D. Bedell. 1960. **White and red pine: ecology, silviculture and management.** Canada Forestry Branch Bul. 124, 185 pp.

This monograph deals with the ecology, silviculture, and management of white pine and red pine throughout their ranges but with particular emphasis on their behavior in the Great Lakes-St. Lawrence Forest Region of Canada. Because of the relationship between the two species in that region, the monograph is both a treatment of the white pine-red pine forest type and a comparative study of the two species. An extensive bibliography is used in documenting the material presented.

Ionov, M. I. 1939. **(Weymouth pine plantations.)** Lesnoe Khozyaystvo (Moscow) 11: 34-37. (In Russian.)

The Weymouth pine plantations of the Tamtov-Ryazan region, now over 30 years old, show good growth and health and have almost twice as large a standing volume per unit area as comparable Scots pine woods in the same region.

Lake States Forest Experiment Station. 1935. **The forest situation in the central pine district, Minnesota.** U. S. Forest Serv. Lake States Forest Expt. Sta. Econ. Note 3, 19 pp.

This was a highly productive unit with large local markets, but after 80 years of lumbering most of the area had been cut over and was still suffering from forest fires. There were approximately 2½ billion board feet of sawtimber standing, nearly half of it scattered on cut-over land. Roughly 1 billion board feet was of pine and other softwoods.

Litscher, B. 1908. **Die Weymouthskiefer in den Stadtwaldungen von Rapperswil.** Schweiz. Ztschr. f. Forstw. 59: 7-14, illus.

In the 1850's a mixed planting of white pine and six other species was made at elevations between 1,200 and 1,500 feet in St. Gallen Canton. It grew rapidly and practically eliminated the other species. Seed production began 20 years after planting and regeneration has taken place on both dry and wet ground, in openings and under considerable shade. At 52 years some trees were 25 inches in diameter and 90 feet tall.

McGuire, John R., and Robert D. Wray. 1952. **Forest statistics for Vermont.** U. S. Forest Serv. Northeast. Forest Expt. Sta., 47 pp.

A report on the ownership and condition of forest areas, timber volumes, and growth and drain, by species, major types, and watersheds. White pine types comprise 11% of the commercial forest area. White pine accounts for about 5% of the primary growing stock and 7% of the sawtimber volume of the State. Most of the white pine area is in the Champlain Valley.

Morey, H. F. 1939. **Research problems in the management of northern white pine in the northeastern United States.** Iowa State Col. Forester 27: 41-47. Ames.

A brief description of the pine region is followed by an outline of the major research problems of the region. The selection system of cutting in pine-hardwood stands appears to offer possibilities that have been little explored.

Northeastern Forest Experiment Station. 1950. **Forest statistics for New Hampshire.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Forest Survey Release 9, 56 pp.

A report of the ownership and condition of forest areas, timber volumes, and growth and drain, by species, major forest types, and counties. White pine types comprise 29% of the commercial forest area. White pine accounts for about 22% of the primary growing stock and about one-third of the sawtimber volume of the State. Most of the white pine area lies in the southern half of the State.

Northeastern Forest Experiment Station. 1954. **The forest resources of New Hampshire.** U. S. Dept. Agr. Forest Resource Rpt. 8, 39 pp., illus.

A summary of the resource situation in New Hampshire, where 29% of the commercial forest area is in white pine or related forest types. The total volume of white pine is 870 million cubic feet, of which roughly ¾ is in sawtimber stands. The sawtimber volume is 3.8 billion board-feet. The annual drain of all softwood sawtimber (¾ of which is white pine) exceeds the annual growth by about 10 million cubic feet.

Northeastern Forest Tree Improvement Conference. 1954. **Northeast. Forest Tree Improve. Conf.** Proc. 1, 107 pp.

Contains papers and discussions of need for and progress in research in genetics of white pine and other species. See Foster (1954), Hansbrough (1954), Brown (1954), Wright (1954), Doran (1954), Rhodes (1954), and Johnson (1954).

Pinchot, Gifford. 1897. **White pine (and) white pine forests.** ***In*** **Timber Trees and Forests of North Carolina.** N. C. Geol. and Econ. Survey Bul. 6: 123-125, 215-219, illus.

A brief description of the species, its growth, its enemies, and its uses. Discusses the condition and occurrence of merchantable stands in North Carolina on the southern and eastern slopes of the Blue Ridge and on the low hills to the west.

Pourtet, J., and P. Duchaufour. 1946. **Possibilities d'utilisation en France de quelques essences Canadiennes.** Rev. des Eaux et Forets 84: 128-152.

White pine is one of many Canadian species considered for silvicultural and utilization possibilities in France. Results so far obtained there are outlined. Notes on its economic value and natural history in North America provide a background for discussion.

Rohmeder, E. 1931. **Anbauflache und Gefahrdungen der Strobe im bayerischen Staatswald.** Forstwiss. Centbl. 53: 325-339, illus.

In the State forest area in Bavaria, white pine suffers from many enemies. Deer are especially destructive to young saplings, on which they rub their antlers. Blister rust attacked 1,677 hectares in 1926, and the fungus *Agaricus melleus,* severely damaged the stand on 1,121 hectares. White pine is relatively free from snow breakage at low altitudes, but is badly damaged above 600-750 meters. Scale insects, weevils, mice, woodpeckers, and drought caused some damage locally.

Ruzicka, Jaroslav. 1939. **Vejmutovka.** ***(Pinus strobus.)*** Lesnická Práce 18 (3): 126-148.

White pine, introduced into central Europe in 1755, is one of the most valuable exotic trees planted there. Its site requirements and growth habits and the quality and uses of the wood are outlined. (German summary.)

Sakss, K. 1949. **Sveszemju koku sugu ieaudzesanas meginajumi dazas Latvijas PSR vietas. (Researches on acclimatization of some foreign tree species in different regions of the Latvian S.S.R.)** Mezsaimniecibas Problemu Instituta Raksti, Latvijas PSR Zinatnu Akademija Riga 1: 7-36, illus.

An account in some detail, with numerous illustrations and graphs, of exotics that have established themselves in some numbers in various parts of Latvia. Some, including white pine, appear to have become completely acclimatized. They survived even the hard winter of 1939-40 without much damage and have regenerated naturally.

Society of American Foresters, New England Section. 1952. **Important tree pests of the Northeast.** Ed. 2, 191 pp., illus.

White pine is listed as one of the hosts of 12 insects (4 of them sawflies) and 5 diseases (3 of them rots) important in the forests of the Northeast. The distribution, hosts, symptoms, damage, life history, and control of these pests are briefly described.

Spalding, V. M.; revised by B. E. Fernow; with contributions by F. H. Chittenden and Filbert Roth. 1899. **The white pine *(Pinus strobus* Linnaeus).** U. S. Div. Forestry Bul. 22, 185 pp., illus.

This early monograph deals primarily with the natural history, distribution and associated species, botanical description, morphology, and wood anatomy; measurements of size, volume, and growth of trees from seedling stage to maturity (based on detailed measurements of 700 widely scattered trees); and insects attacking the species. The white pine lumber industry, available supplies of timber, and the qualities and uses of the wood are also described.

Takahashi, N. 1951. **Silvicultural value of white pine in Hokkaido.** Tokyo Univ. Forest Misc. Inform. 8: 1-11.

White pine is recommended in preference to *Picea jezoensis, Abies sachalinensis,* Japanese larch, or Norway spruce because it is suited to the climate, grows fast, is rarely damaged by rats, is suitable for a wide variety of sites and is easy to raise from seed, and because the wood has many uses. Data for these conclusions are drawn from literature and from 66 hectares of white pine, pure and in mixture, in the Tokyo University Forest.

TAXONOMY : PLANT STRUCTURE : GENETICS

Anonymous. 1890. **A bit of forgotten history.** Garden and Forest 3: 536.

Presents reasons for believing that a young pine at Fontainbleau, identified in 1553 by Pierre Belon as *Pinus cembra,* was really *Pinus strobus.* This would antedate Lord Weymouth's first cultivation of white pine in England by about 150 years.

Abbe, Lucy B., and A. S. Crafts. 1939. **Phloem of white pine and other coniferous species.** Bot. Gaz. 100: 695-722, illus.

In white pine, cambial division may start as early as February and is rapid during May. Phloem differentiation may lag until late summer or early fall, and daughter cells may remain in various stages of maturity through the winter. The structural and physiological changes that accompany sieve-tube differentiation, functioning during maturity, and approach to senility are described.

Bailey, I. W. 1920. **The cambium and its derivative tissues. II. Size variations of cambial initials in gymnosperms and angiosperms.** Amer. Jour. Bot. 7: 355-367.

The dimensions of cells in and near the cambium differed greatly in the wide variety of species studied. In white pine the lengths of cambial initials ranged from 2.3 to 4.0 mm., with an average of 3.2 mm. The length of tracheids varied from 2.2 to 4.6 mm., with a mean of 3.4 mm. The means were from 50 measurements.

Bailey, I. W. 1920. **The cambium and its derivative tissues. III. A reconnaissance of cytological phenomena in the cambium.** Amer. Jour. Bot. 7: 417-434, illus.

Using white pine material primarily, it was determined that cambial initials may attain a length of 9,000 microns or more — several hundred times the width. They are uninucleate, and the nucleo-cytoplasmic ratio may be relatively constant in ray initials but is highly variable in fusiform initials. All initials have the diploid (24) number of chromosomes, which are as large in small ray initials as in large fusiform initials.

Bailey, I. W. 1923. **The cambium and its derivative tissues. IV. The increase in girth of the cambium.** Amer. Jour. Bot. 10: 499-509.

Measurements of the number and size of fusiform initials in white pine sections of various ages are used to illustrate that, in species with nonstratified cambia, increase in the girth of the cambium is caused primarily by the elongation and consequent crowding of the fusiform initials in any given section.

Bailey, I. W. 1930. **The cambium and its derivative tissues. V. A reconnaissance of the vacuome in living cells.** Ztschr. f. Zellforsch. u. Mikros. Anat. 10: 651-682, illus.

In all species studied (hardwoods and softwoods, including white pine) the cambial cells were conspicuously vacuolated but the form differed with species and season. Changes in the vacuole appear to be due to a complex of varying physio-chemical factors, affecting both the protoplasm and the content of the vacuoles, rather than solely to hydration and dehydration of vacuolar colloids. Describes technique for studying living cells.

Baker, Lillian V. 1920. **Vestigial centripetal xylem and transfusion tissues in the leaf of *Pinus strobus*.** Roy. Soc. Canada Trans. vol. 3, ser. 5, soc. 14: 51-69, illus.

Morphological studies of cotyledonary, primordial, normal, and polyphyllus adult leaves of white pine have given evidence on the origin of transfusion elements — the parenchyma-shaped tracheids bordering the fibrovascular bundle. Author concluded that these elements originate from parenchyma rather than from centripetal xylem, the secondary wood, or the fossil sheaths as claimed by various other investigators.

Brown, H. P. 1921. **White pine, Weymouth pine. *In* Trees of New York State, Native and Naturalized.** N. Y. State Col. Forestry Tech. Pub. 15: 76-77.

A brief description of the silvics and distinguishing characteristics of eastern white pine.

Burt, L. B. 1939. **The bearing of Zalanski's law on conifer leaves.** Kansas Acad. Sci. Trans. 42: 113-121.

Investigations on leaves of white pine and eight other conifers showed that photosynthetic cells decreased in size and increased in frequency from the basal to the apical parts. The stomatal frequency increased in the same direction. This bears out the observations made by Zalenski and others on plants in general.

Delisle, Albert L. 1942. **Histological and anatomical changes induced by indoleacetic acid in rooting cuttings of *Pinus strobus* L.** Va. Jour. Sci. 3: 118-124, illus.

Cuttings and brachyblasts from 4-year-old seedlings of white pine root readily after auxin treatment, but brachyblasts are not able to survive unless a terminal bud is also formed. Anatomical changes in response to the auxin take place first in the cortex and then in the cambium. These changes and the resulting root anlagen are associated by position with rays and leaf traces.

Duffield, J. W., and F. I. Righter. 1953. **Annotated list of pine hybrids made at the institute of forest genetics.** U. S. Forest Serv. Calif. Forest and Range Expt. Sta. Forest Res. Note 86, 9 pp.

Among the hybrids produced at Placerville, Calif., were three with eastern white pine parents. Western white x eastern white, 1939, was produced from several geographic races of each parent. All individuals have hybrid vigor and some seem resistant to blister rust. Western white x (Balkan white x eastern white), 1946, grows as fast as the one above and is being tested for blister rust resistance. Eastern white x Himalayan white, 1940, has shown good blister rust resistance and grows faster than eastern white pine.

Ferguson, Margaret C. 1901. **The development of the pollen-tube and the division of the generative nucleus in certain species of pines.** Ann. Bot. 15: 193-223, illus.

Pollination took place from late May to early June. The pollen grain germinated soon after and the vegetative nucleus moved immediately into the pollen tube, which grew very slowly during the first season. Shortly before fertilization the stalk cell moved into the pollen tube and the generative nucleus divided. Fertilization of the egg took place 10 days after nuclear division and 13 months after pollination. Development was essentially the same in the five species studied.

Ferguson, Margaret C. 1904. **Contribution to the knowledge of the life history of pinus with special reference to sporogenesis, the development of the gametophytes and fertilization.** Wash. (D. C.) Acad. Sci. Proc. 6: 1-202, illus.

The standard reference on the subject. Three trees each of *Pinus strobus, P. rigida, P. austriaca, P. montana* var. *uncinata* and *P. resinosa* provided the study material, collected periodically from November 1897 to July 1899. The development of staminate and pistillate flowers was followed from their first appearance until fertilization. The results are covered under the chapter headings: microsporogenesis; the male gametophyte; macrosporogenesis; the female gametophyte; fertilization and related phenomena.

Fielding, J. M. 1951. **The chiapas white pine.** Austral. Forestry 15: 114.

A note on a variety of white pine found in Mexico and Guatamala, that makes very rapid growth and apparently produces wood of good quality.

Grahle, Annelise. 1933. **Vergleichende Untersuchungen über strukturelle und osmotische Eigenschaften der Nadeln verschiedener Pinus-Arten.** Jahrb. f. Wiss. Bot. 78: 203-294, illus.

Among 29 pine species studied, the needles of white pine had the greatest ratio (87) of surface area to volume and ranked among the species whose needles had the greatest percentage of assimilatory (56%) and epidermal (25%) tissue and the smallest percentage of conducting tissue (19%). The needles of white pine had the greatest number of stomata per unit volume (311 per cubic mm.) but were intermediate in number per unit surface (37 per square mm.).

Harlow, W. M. 1931. **The identification of the pines of the United States, native and introduced, by needle structure.** N. Y. State Col. Forestry Tech. Pub. 32, 21 pp., illus.

Discusses morphology and anatomy of the needles and gives a key to identification of the species, based on needle structure. Includes photomicrographs and an index to the common and scientific names.

Heimburger, C. C., and L. P. V. Johnson. 1946. **Preliminary report on interspecific hybridization in forest trees.** Canad. Jour. Res. Sec. C. 24: 308-312.

A report on work from 1938 to 1945 at Chalk River, Ontario, and the Dominion Arboretum, Ottawa. Successful crossing of *P. strobus* and *P. peuce* is reported, with 55% seed set, 6% germination, and 62 seedlings produced with a survival of 70%. There were sufficiently large trials in crossing *P. strobus* with *P. koraiensis* and *P. resinosa* to make these failures worth reporting.

Huet, M. 1933. **Determination de differentes especes de pins par l'etude anatomique de l'aiguille.** Soc. Cent. Forest. de Belg. Bul. 40: 66-75, 107-139, illus.

White pine is one of 36 species of pine classified and keyed according to anatomical characteristics of the needles. The transverse section of a white pine needle is illustrated and described in detail. The differences between white pine and closely related species are emphasized.

Johnson, Albert G. 1952. **Spontaneous white pine hybrids.** Jour. Arnold Arbor. 33: 179-187, illus.

A small hybrid group of *Pinus strobus parviflora* is described, and the type individual is designated X *P. hunnewelli.* It displays marked heterosis and is promising as an ornamental because of its attractive foliage. The hybrid is at least partially fertile and is readily propagated by common grafting techniques. A second hybrid between *P. peuce* and *P. parviflora* is also referred to.

Johnson, L. P. V. 1939. **The breeding of forest trees.** Forestry Chron. 15: 139-151.

A brief review of the techniques available for improving forest trees, and the possible applications of these techniques. One white pine at Petawawa has been observed to be exclusively female. In white pine there is a definite tendency for the female flowers to mature before the male flowers, which are borne on the lower branches.

Johnson, L. P. V. 1943. **The storage and artificial germination of forest tree pollens.** Canad. Jour. Res., Sect. C. 21: 332-342.

Pollen from the pines and spruces proved to have the greatest longevity in storage. The best physical and nutrient conditions for pine pollen was 10% sucrose in 0.75% agar. Incubation in light or dark made no significant difference in germination, but pollen-tube growth was stimulated by light. After 1 year of storage, white pine pollen held in the dark at 2° C. and at 35-75% relative humidities gave best germination (more than 90%).

Johnson, L. P. V. 1945. **Reduced vigor, chlorophyll deficiency and other effects of self-fertilization in *Pinus*.** Canad. Jour. Res., Sect. C. 23: 145-149, illus.

Selfed white pine seeds showed no appreciable difference from open-pollinated or hybridized seed in seed set or in seedling emergence but in seedlings 4 years old, those from selfed seed were significantly smaller and had pronounced chlorophyll deficiency in 11 out of 46 seedlings. Other detrimental effects of selfing are shown for other pines.

Kelsey, Harlan P., and William A. Dayton. 1942. **Standardized plant names.** Ed. 2, 675 pp. Harrisburg, Pa.

A revised and enlarged listing of approved scientific and common names of plants and plant products in use in America. *Pinus strobus* and *eastern white pine* are the approved scientific and common names. Scientific variety names and lumber trade names associated with white pine are also listed.

Kerr, Thomas, and I. W. Bailey. 1934. **The cambium and its derivative tissues. X. Structure, optical properties, and chemical composition of the so-called middle lamella.** Jour. Arnold Aboretum 15: 327-349, illus.

A study in which most of the work was done with white pine and later checked with other species has shown that the middle lamella, commonly considered a single isotropic homogeneous membrane, is two lignified anisotropic cambial walls and an intervening, truly isotropic layer of lignified material.

Kozlowski, Theodore T., and Francis X. Schumacher. 1943. **Estimation of stomated foliar surface of pines.** Plant Physiol. 18: 122-127, illus.

The surface area of a population of pine needle fascicles may be readily calculated through its correlation with volume, a value more easily determined by displacement. The methods are described, and expressions suitable for loblolly and eastern white pine are given.

Little, Elbert L., Jr. 1953. **Check list of native and naturalized trees of the United States (including Alaska).** U. S. Dept. Agr., Agr. Handbk. 41, 472 pp.

White pine, which was named by Linnaeus in 1753 from the Latin *strobos* (pine cone), ranges from Newfoundland west to southeastern Manitoba. In the east it ranges south to northern Georgia and in the west to northeastern Iowa.

Meyer (first name not given). 1953. **Der Bastard *Pinus strobus* x *excelsa*.** Cong. Internatl. Union Forest Res. Organ. Proc. Sect. 22 (13). 2 pp.

A 16-year-old hybrid from the arboretum at Hanover Munden shows signs of hybrid vigor and of resistance to attack by *Cronartium ribicola*. A good seed yield with 82% viability was obtained from experimental crosses in 1951.

Meyer, H. 1954. **Zur Blasenrostresistenzzüchtung mit Pinus strobus.** Ztschr. f. Forstgenetik 3: 101-104, illus.

Of 32 healthy older trees selected for blister rust resistance, 4 clones have proved non-resistant. The hybrid *Pinus strobus* x *P. griffithii* can be successfully produced and has proved resistant. One such hybrid, now 17 years old, has shown remarkable growth and vigor.

Nieuwland, Julius A. 1913. **The generic name of the white pine.** Amer. Midland Nat. 3: 68-70.

It is argued that the white pine should be separated taxonomically from the other pines. The generic name *Leucopitys,* from the Greek words meaning "white" and "pine," is proposed for *Pinus strobus* and *P. excelsa,* the specific names to remain the same.

Perry, G. S. 1940. **Keys to the pines of the Tennessee Valley.** Rev. ed., 12 pp. T.V.A. Dept. Forest Relat.

Three keys to the pines are given: (1) needle and twig, (2) cone, and (3) natural occurrence. White pine is one of the six native species, and five introduced species are also included.

Righter, F. I. 1945. **Pinus: the relationship of seed size and seedling size to inherent vigor.** Jour. Forestry 43: 131-137, illus.

The results of a series of tests with several species and species hybrids show that seed size and seedling size are controlled more by environment than by heredity. In one test *Pinus monticola* x *P. strobus* was compared with natural progeny of *P. strobus*. Data indicated that selection for inherent vigor based on height at 1 or 2 years would be unreliable because at 3 years the height of *P. strobus* expressed as a percentage of the hybrid height is considerably greater than it was at 1 and 2 years. Early height was primarily an expression of seed size and other non-heritary factors.

Riker, A. J., and R. F. Patton. 1954. **Breeding of *Pinus strobus* for quality and resistance to blister rust.** Wis. Univ. Forestry Res. Note 12, 2 pp.

A resumé of the white pine improvement program at the University of Wisconsin. Since 1938 more than 200 selections for blister rust resistance have been made from natural stands in Wisconsin and Minnesota; some 40 of them show great promise after tests in the blister rust nursery. Since 1949, 185 successful intra-specific crosses have been made and are being tested for resistance. Some interspecific crosses have been made and some of these between resistant eastern and western white pine have shown marked hybrid vigor when 2 years old.

Sargent, Charles Sprague. 1902. ***Pinus strobus*, white pine. *In* The silva of North America** 11: 17-22, illus.

In his principal work, Sargent has compiled information on synonymy; distribution; size, habit, and other dendrologic characteristics; properties of the wood; products of the tree; and economic history. Excellent plates illustrate details of twigs and cones. Copious footnotes cite early authors on distribution, size, and other historical items.

Sax, Karl, and Hally Jolivette Sax. 1933. **Chromosome numbers and morphology in the conifers.** Jour. Arnold Arboretum 14: 356-375, illus.

A highly technical paper reporting the chromosome numbers of 53 species in 16 genera of conifers and the chiasma frequency and behavior of the chromosomes at meiosis of 22 species in 10 genera. White pine has a chromosome number of 12 and an average number of chiasmata per bivalent of 2.4.

Schreiner, E. J., and M. A. Huberman. 1940. **Induced flowering — a tool for mass selection, progeny tests, and forest management.** Jour. Forestry 38: 491-492.

Describes ways by which flowering may be induced in forest trees. Induced flowering should prove useful to the practicing forester, because harvest cuttings can be made to coincide with seed years and seed need be collected only from trees of known superior quality.

Shaw, G. R. 1914. ***Pinus strobus*. *In* The genus pinus.** Arnold Arboretum Pub. 5, 96 pp., illus.

White pine was originally described by Linnaeus in 1753. Three synonyms are given, and botanical features and general characteristics are described. Classification is based on the evolution of cones and seeds. White pine is placed in *Section Haploxylon, Subsection Cembra, Group Strobi.*

Small, John Kunkel. 1913. **Flora of the southeastern United States.** 1370 pp. New York.

Primary generic differences among pine species are the number of needles per fascicle and the number of fibro-vascular bundles per needle. White pine is the only species described in the genus that has five needles per fascicle and one fibro-vascular bundle per needle.

Spurr, Arthur R. 1949. **Histogenesis and organization of the embryo in *Pinus strobus* L.** Amer. Jour. Bot. 36: 629-641, illus.

Describes the later stages of embryogeny of white pine, with particular regard to the origin of the parts and tissue systems.

Spurr, Arthur R. 1950. **Organization of the procambium and development of the secretory cells in the embryo of *Pinus strobus* L.** Amer. Jour. Bot. 37: 185-197, illus.

Well-defined patterns of organization occur in each of the two portions (xyloic and phloic) of the procambium. They are distinguished by rather consistent differences in general cell form and size. Two categories of secretory cells are also recognized — vascular and subdermal.

Thomson, Robert Boyd. 1914. **The spur shoot of the pines.** Bot. Gaz. 57: 362-385, illus.

Argues that spur shoots in pines are specialized, not primitive, characters and that they are wholly vegetative, not vestigial reproductive, in function. The lack of definiteness in the number of leaves in a fascicle, and the occurrence of supernumerary needles in the recognized primitive region and after wounding, are evidence of the branch character of the spurs.

Wright, Jonathan W. 1951. **Tree-breeding technique: some effects of continuous bagging.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Forest Res. Note 5. 4 pp.

Describes the case of one white pine at Philadelphia, which normally matured only 5% of its cones and yielded no viable seed but after continuous bagging yielded 49 seeds from the 2 cones that matured from the 5 strobili pollinated.

Wright, J. W. 1952. **A directory of forest genetics research in the United States and Canada.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 53. 7 pp.

Gives location, personnel, and nature of work on 10 projects with white pine.

Wright, Jonathan W. 1953. **Summary of tree breeding experiments by the Northeastern Forest Experiment Station, 1947-1950.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 56, 47 pp., illus.

Cone mortality and low seed yield were generally common in the pines, especially white pine. The following true hybrids were bred: *Pinus griffithi* x *P. strobus* and reciprocal, *P. strobus* x *P. flaxilis, P. strobus* x *P. ayacahuite, P. strobus* x *P. parviflora.* A probable hybrid *P. peuce* x *P. strobus* was also obtained.

Wright, Jonathan W. 1954. **Racial variation and individual tree selection in the Northeast.** Northeast. Forest Tree Improve. Conf. Proc. 1:

Notes that the possibility of there being more than one geographic race in white pine has not been investigated. Work in Wisconsin has shown that there are individual white pines sufficiently resistant to blister rust to make possible the breeding of a resistant strain.

Zirkle, Conway. 1931. **Nucleoli of the root tip and cambium of *Pinus strobus*.** Cytologia 2: 85-105, illus.

The root tip and cambium were fixed in several different fluids to preserve the chromatin plastin and mitochondria in several different combinations. It was thus possible to follow the plastin through the mitotic phases and to distinguish between plastin and mitochondria in the cytoplasm. The organization of nucleolar material and its behavior during karyokinesis are described.

CHEMISTRY AND PHYSIOLOGY : CYTOLOGY

Bailey, I. W. 1930. **The cambium and its derivative tissues. V. A reconnaissance of the vacuome in living cells.** Ztschr. f. Zellforsch. u. Mikros. Anat. 10: 651-682, illus.

A technique was perfected for studying living cells of the cambium and its derivative tissue. Cambial initials could be kept alive and actively streaming for 500 hours after sections were cut. A study was made of cell vacuoles in a number of softwoods (including white pine) and hardwoods. In all species the cambial cells were conspicuously vacuolated but the form differed with species and with season.

Burkholder, Paul R., and Ilda McVeigh. 1945. **The b vitamin content of buds and shoots of some common trees.** Plant Physiol. 20: 276-282.

The content of eight vitamins in the needles of eastern white pine and eastern hemlock and in the buds of a number of hardwood trees and shrubs is given. It is suggested that vitamins are among the specific substances making up plant auxins.

Burns, George P. 1926. **Relation of the moisture content of the soil to the sensitiveness of the chloroplast to light.** Vt. Agr. Expt. Sta. Bul. 257, 16 pp., illus.

One potted white pine seedling and a few of other species were used to determine the relation between soil moisture content and rate of photosynthesis as measured by the gain or loss of carbon dioxide in the air.

Burns, G. Richard. 1936. **Further studies of the limits of photosynthesis.** Vt. Agr. Expt. Sta. Bul. 402, 16 pp.

Describes results of a study of the limits of photosynthesis of white pine and Norway spruce under short- and long-wave light. Seedlings grown under red, blue, and white light for various periods were placed under red and blue light and the rate of photosynthesis was determined. It appears that these species cannot use light in the blue-violet portion of the spectrum as well as they can the light near the center of the spectrum.

Burns, G. Richard. 1937. **Photosynthesis and the absorption spectra of plant pigments.** Amer. Jour. Bot. 24: 257-265.

The primary absorption spectrum of a plant is defined as the incident radiation minus the reflected radiation minus the radiation transmitted by a solution of the plant pigments in 85% acetone similar in concentration to that in the leaf. On the assumption that only light thus primarily absorbed was effective in photosynthesis, that the quantum yield did not change, and that the long-wave limit of photosynthesis was 7800 A, the relative amounts of photosynthesis in various portions of the spectrum down to 5000 A were calculated for white pine. The observed values agreed with the calculated values within a few percent.

Burns, G. Richard. 1942. **Photosynthesis and absorption in blue radiation.** Amer. Jour. Bot. 29: 381-387.

Data on the relative photosynthetic efficiencies of white pine, Norway spruce, and Marquis wheat in monochromatic radiation at several wave lengths.

Chandler, R. F. 1939. **The calcium content of the foliage of forest trees.** Cornell Agr. Expt. Sta. Mem. 228, 15 pp., illus.

In white pine the calcium content of the needles increased through each growing season (to about 0.5% of dry weight during the first season and to about 0.9% during the second season) but remained fairly constant during the winter. By the end of the third growing season the mature white pine leaves had a calcium content of 1.2% — about the same as mature leaves of white oak, red oak, chestnut oak, yellow birch, and balsam fir.

Dole, Eleazer J. 1924. **Studies on the effects of air temperature and relative humidity on the transpiration of *Pinus strobus*.** Vt. Agr. Expt. Sta. Bul. 238, 39 pp., illus.

Experiments with a few white pine seedlings in the greenhouse and in the field demonstrated that transpiration was very responsive to environmental changes. Transpiration loss could not be correlated with relative humidity, temperature, or vapor pressure; but the product of loss and vapor pressure was correlated with temperature. This indicates an additional effect of temperature which may be interpreted in terms of diffusion.

Doyle, Joseph, and P. O'Connor. 1930. **Seasonal change in the catalase content of conifer leaves.** Ann. Bot. 44 (176): 907-915.

Measurements of catalase activity of conifer leaves in summer, fall, and winter are reported. In white pine and seven other conifers, catalase activity was invariably greater in October than in July, and in January than in October.

Duffield, John W., and Albert G. Snow, Jr. 1941. **Effect of storage conditions on pollen longevity of *Pinus strobus* and *Pinus resinosa*.** Jour. Forestry 39: 410-411, illus.

After 1 year's storage at 50% relative humidity and 0 to 4° C., pollen of both pine species had 80% germinability — definitely greater than pollen stored under warmer and more humid conditions.

Ehlers, John Henry. 1915. **The temperature of leaves of *Pinus* in winter.** Amer. Jour. Bot. 2: 32-70.

As an adjunct to the main experiments reported, leaves of white pine and several other conifers were collected throughout January, February, and March in southern Michigan. There was no evidence of starch formation in white pine during the period, although there was in the other species.

Fraser, D. A. 1949. **Production of spring wood with B-indole-acetic acid (heteroauxin).** Nature 164: 542.

Applications of heteroauxin tended to cause production of spring wood tracheids with large radial measurements and narrow walls; in contrast, the controls formed thicker and narrower tracheids typical of summerwood. White pine was used as the test material.

Fraser, Donald A. 1952. **Initiation of cambial activity in some forest trees in Ontario.** Ecology 33: 259-273.

Cambial activity in white pine, *Larix laricina,* and *Picea mariana* was studied by sectioning samples of bark and outer wood and by daily measurements of radial increment with a dendrometer. Cambial activity proceeded from the apex to the base of the tree. Experiments with heteroauxin and a lengthened photoperiod substantiated the theory of a stimulus not associated with food, proceeding from the buds and developing leaves in the spring and being responsible for the apical initiation of cambial activity.

Fraser, D. A., and C. A. Mawson. 1953. **Movement of radioactive isotopes in yellow birch and white pine as detected with a portable scintillation counter.** Canad. Jour. Bot. 31: 324-333, illus.

Calcium-45 chloride and calcium chloride were introduced in bore-holes in two bifurcated white pines on July 10. One stem received the chemical and the other was used as a control. The isotope moved upward from the point of injection in a relatively narrow channel. Only two branches contained appreciable activity. Monitering on August 22 indicated an accumulation of isotope in the main stem at a point where the upper active branch had its origin, and from here most of the radioactive calcium was carried out into this branch.

Freeland, R. O. 1952. **Effect of age of leaves upon the rate of photosynthesis in some conifers.** Plant Physiol. 27: 685-690, illus.

Under uniform conditions of light, temperature, and CO_2 concentration, apparent photosynthetic rate of leaves 1 to 3 years old of white pine and four other conifers was measured by the difference in CO_2 content of air passed over the needles. Rate of photosynthesis decreased with increase in age; in white pine the decrease was small and in 3-year-old needles photosynthesis was still appreciable.

Gibbs, R. Darnley. 1939. **Studies in tree physiology. I. General introduction. Water contents of certain Canadian trees.** Canada Jour. Res. Sect. C. 17: 460-482.

Water content of entire 2-year-old twigs, 1-year-old twigs, and needles from old white pine in Quebec was determined at different times during the winter. In November, December, and January water content was apparently constant, roughly 110-140% of dry weight. By mid-March, water content dropped to 96-130%. By mid-April it had increased to 117-142%.

Koblet, Rudolf. 1937. **Uber die proteolytisene Aktivität von Weymouthskiefern-und Weizensamen unter besonderer Berudksichtigung des Einflusses der Vorkühlung.** Internatl. Seed Testing Assoc. Proc. 9: 228-253.

In tests with embryos and endosperms (white pine and wheat seeds) it was shown that low temperatures had no beneficial influence on proteolytic activity, which in turn could not be the factor influencing germination. The rapid breaking down of reserve proteins during germination is connected with the removal of the products of hydrolysis due to the growth processes in the embryo, as well as with the rise in the activity of proteolytic enzymes.

Kozlowski, Theodore T. 1943. **Transpiration of some forest tree species during the dormant season.** Plant Physiol. 18: 252-260, illus.

An experiment with potted trees in the open at Durham, N. C., established differences in transpiration per unit of transpiring surface with season and species. The average transpiration of white pine in October and November was more than three times the maximum transpiration in December and January.

LaRue, Carl D. 1936. **Cell outgrowths from wounded surfaces of plants in damp atmospheres.** Mich. Acad. Sci. Arts and Letters Paper 22: 123-139.

When 1- to 3-year-old white pine twigs were cut into short sections, split, and placed in damp chambers, outgrowths developed between the cambium and the xylem, between the cambium and the cortex, and in the cortex itself.

Loewenberg, J. B., and F. Skoog. 1952. **Pine tissue cultures.** Physiol. Plant. 5: 33-36.

A method and media for obtaining callus and maintaining growth of tissue cultures of red and white pine are described. A heat labile factor present in malt and pine seed appears to be essential for the growth of red pine cultures.

Lorenz, R. W. 1939. **High temperature tolerance of forest trees.** Minn. Agr. Expt. Sta. Tech. Bul. 141. 25 pp., illus.

The cortical parenchyma cells in microscopic sections from seedlings of white pine and four other species were killed in 30 minutes when exposed to temperatures between 57 and 59° C. by immersion in a water bath, and in 1 minute at 65 to 69° C. The five species did not vary markedly in their relative heat resistance.

Maki, T. E., and H. Marshall. 1945. **Effects of soaking with indolebutyric acid on root development and survival of tree seedlings.** Bot. Gaz. 107: 268-276.

Preliminary experiments in 1942 showed no beneficial responses to root soaking of white pine.

Parker, Johnson. 1952. **Dessication in conifer leaves: anatomical changes and determination of the lethal level.** Bot. Gaz. 114: 189-198.

Gives results of studies of the changes in needles of *Pinus nigra* var. *austriaca* and white pine during gradual drying and rehydration, including rate of CO_2 release from drying needles. Usefulness of the tetrazolium chloride test as a measure of viability is discussed.

Riou, Paul, Gerard Delorme, and (Le Frere) Hormisdas. 1936. **De la distribution du manganese et du fer dans les pins du Quebec.** Acad. de Sci. Compt. Rend. 202 (21): 1811-1812.

Report on an investigation of the distribution of manganese and iron in the bark, branches, leaves, sapwood, heartwood, and seeds of Quebec-grown *Pinus strobus, P. resinosa,* and *P. banksiana.* Amounts of iron and manganese varied inversely. The metals were found in leaves and branches, and seem to accumulate in the bark.

Struckmeyer, B. Ester, and A. J. Riker. 1951. **Wound periderm formation in white-pine trees resistant to blister rust.** Phytopath. 41: 276-281, illus.

Cortex and phloem tissues of normal white pines and of susceptible and resistant white pines that had been artificially inoculated with blister rust 4 years earlier were examined. Resistant trees were not immune to attack; but the infected cells were effectively walled off from healthy tissue by wound periderm of suberized cork cells and lignified stone cells. In susceptible trees there was little or no evidence of wound periderm, so the mycelium easily penetrated the phloem to the cambium, eventually killing the tree.

Voight, G. K. 1953. **The effects of fungicides, insecticides, herbicides, and fertilizer salts on the respiration of root tips of tree seedlings.** Soil Sci. Soc. Amer. Proc. 17: 150-152, illus.

Studies with excised root tips in nutrient solutions and with seedlings in quartz sand and the A_1 horizon of outwash sand indicate that biocides (calomel, spergon, thiosan, Stoddard oil, and chlordane) influence the oxygen uptake in root tips of white pine and several other species. Results vary with species, chemical, and fertilization. The manometric technique is suitable for such studies.

Wallace, R. H. 1932. **The photosynthetic activity of evergreens in winter.** Ecol. Soc. Amer. Bul. 13, item 35.

Tests showed that some photosynthetic activity occurred in white and red pine, hemlock, and a number of other softwoods at temperatures below 10° C.

White, Donald P. 1954. **Variation in the nitrogen, phosphorus, and potassium contents of pine needles with season, crown position and sample treatment.** Soil Sci. Soc. Amer. Proc. 18: 326-330.

Plantations in New York were systematically sampled and analyzed by standard chemical procedures. Data on magnitude of variations in red and white pine confirm the percentage decline of K, N, and P in needle tissue from an early summer maximum to a fairly constant base level during winter months. Late fall and winter sampling from mid-crown is recommended for foliar analysis. Stripping of needles from branches and immediate oven-drying (70° C.) after collection is necessary.

Zeeuw, Carl de. 1941. **Influence of exposure on the time of deep cork formation in three northeastern trees.** N. Y. State Col. Forestry Tech. Pub. 56, 10 pp., illus.

In studies of white pine (red ash and yellow-poplar were also used) it was found that the mean age of deep cork formation in open-grown trees was 20 years whereas the mean age in trees that had grown in stands with full crown closure was 35 years, whether the trees were dominants, codominants, or suppressed.

SILVICAL CHARACTERISTICS

Anonymous. 1941. **Seed dissemination of native tree species.** Canada Forestry Branch Silvic. Leaflet 2, 2 pp.

A preliminary report on seed dissemination at the Petawawa Station (Ontario) shows that most white pine seed falls inside the stand between October 3 and November 11.

Anonymous. 1950. **Effective pollination distances.** *In* U. S. Forest Serv. Northeast. Forest Expt. Sta. Ann. Rpt. 1949: 12-13.

Pollen counts made at varying distances from heavily pollinating trees corroborated observations on the degree of fruitfulness of isolated trees. For white pines near Philadelphia, production of viable seed averaged only 0.3 to 1.8 per cone on trees isolated from pollinating neighbors by 200 feet or more. Distances as short as 100 feet between seed trees may reduce pollination below the requirements for effective seed production.

Badoux, H. 1930. **Recherches sur l'accroissement du pin Weymouth en Suisse.** Jour. Forest. Suisse 81: 14-18.

Report of white pine studies in Switzerland. Describes soil profile in a 36-year-old plantation in Canton Argovie, as well as rooting habits, thinning practices, attack by blister rust, and stand conditions in regard to numbers, basal area, diameter, total height, and volume. Recommends thinning at 2- to 3-year intervals to remove trees infected by blister rust.

Baldwin, Henry I. 1931. **The period of height growth in some north-eastern conifers.** Ecology 12: 665-689, illus.

The period of white pine height growth began April 26 - June 20 and lasted till August 4 - September 5. Rapid growth began early in June and continued through most of the month. Temperature seemed to be the major determinant. White pine always followed the grand-period type of growth, but the curves varied somewhat with place and time; for example, some were double-peaked.

Baldwin, H. I., and M. A. Holden. 1939. **Phenological observations.** N. H. Forestry and Recreation Comn. Fox Forest Notes 17, 1 p.

Records taken at Hillsboro, N. H., over a 5-year period show that for white pine the average date of bud bursting is April 12, the beginning of flowering June 15. Fruit ripens about September 2 and the seed begins to disperse about September 12.

Belyea, R. M., D. A. Fraser, and A. H. Rose. 1951. **Seasonal growth of some trees in Ontario.** Forestry Chron. 27: 300-305.

A brief report on results with a new dial-gage dendrometer used on white pine at Chalk River, Ont., and on other species at Chalk River and Cedar Lake, Ont. White pine growth began about May 25 and was complete by August 25.

Brown, H. P. 1915. **Growth studies in forest trees. 2. *Pinus strobus* L.** Bot. Gaz. 59: 197-241, illus.

A detailed record of seasonal growth was obtained from sections taken periodically, and other measurements. Stages of growth are described in detail. Since moisture conditions and food reserves are at optimum in spring, it appears that awakening and rapidity of growth are directly proportional to prevailing temperatures.

Buckhout, W. A. 1907. **The formation of the annual ring of wood in the European larch and the white pine.** Forestry Quart. 5: 259-267.

Careful measurements of circumference on one tree of each species over a period of 4 years showed that the period of cambial activity in white pine at State College, Pa., was from the last week of April to the first week of September. The trees were in an ornamental setting comparable to an open forest stand.

Burger, Hans. 1930. **Mitteilunge die Weymouthsfohre.** Schweiz. Centralanst. f. Forstl. Versuchsw. Mitt. 15: 243-292.

Data obtained from 24 white pine trees, aged 21 to 70 years and growing in 8 different situations, were used to show relationships among wood quality, growth, and quantity of foliage. To produce a cubic meter of wood per year, 600 to 1,500 kilograms of green needles, or a foliage area of 6,000 to 15,000 square meters, are required.

Cousins, M. 1938. **White pine monarch.** Wis. Mag. Hist. 22: 44-45.

A large white pine cut in Wisconsin in 1937 was about 426 years old, 4 feet 10½ inches in diameter at the butt, and had a total height of 140 feet. Merchantable log length was 92 feet and the logs scaled 5,078 feet board measure.

Deen, J. Lee. 1933. **Some aspects of an early expression of dominance in white pine *(Pinus strobus,* L.).** Yale Univ. School Forestry Bul. 36, 34 pp., illus.

White pine has the inherent ability to express dominance. Good sites and variation of age within the stand favor expression of dominance; dense stocking is detrimental on the poorer sites only. Low density of stocking acts against expression of dominance on all sites but does not cause stagnation. Silvicultural treatment can either favor or check this expression of dominance.

Deen, J. L. 1934. **The expression of dominance after twenty years in a nursery seed bed.** Jour. Forestry 32: 485-486.

Studies of white pine trees in a 20-year-old seedbed indicate strongly that the species possesses inherent characteristics that enable it to show an acceptable expression of dominance on a good site regardless of original density or lack of variation in age.

Friesner, R. C. 1942. **Elongation of the primary axis in four species of pines.** Ind. Acad. Sci. Proc. 1941: 51.

Measurements of terminal internodes in 50 specimens each of white pine, *P. banksiana, P. silvestris,* and *P. resinosa* were made weekly during the period April 1 to September 25, 1941. *P. banksiana* and *P. silvestris* reached their peak growth early in May; white pine and *P. resinosa* showed maximum growth somewhat later in the month.

Friesner, Ray C. 1942. **Vertical growth in four species of pines in Indiana.** Butler Univ. Bot. Studies 5: 145-159, illus.

Elongation was measured weekly on 50 individuals each of jack, Scotch, red, and white pine. Terminal growth began in most individuals the week ending April 13, but in the majority of the white pines it began a week later. All individuals showed a grand-period type of growth with nine different curve-types being displayed. Most of the white pines showed a single peak of growth that was fairly regular. Maximum growth was reached in white pine 4 to 7 weeks after initiation.

Friesner, Ray C. 1943. **Correlation of elongation in primary, secondary, and tertiary axes of *Pinus strobus* and *P. resinosa*.** Butler Univ. Bot. Studies 6: 1-9, illus.

Careful measurements of the elongation of the terminal axis and 30 secondary axes on a single eastern white pine in Indiana at 1- to 3-day intervals verified that the elongation of white pine follows the grand-period type of growth. Growth of all axes began at the same time but the terminal axis grew faster and for a longer period than the secondary axes. The younger secondary axes (near the top of the tree) grew somewhat faster and for a longer period than older ones.

Friesner, Ray C., and Gershon Walden. 1946. **A five-year dendrometer record in two trees of *Pinus strobus*.** Butler Univ. Bot. Studies 8: 1-23.

Weekly measurements taken on two trees at Camden, Maine, throughout a 5-year period showed that true radial enlargement began between April 15 and May 26. The data coincided within a few days with the date on which the mean daily air temperature was continuously above 50° F., and closely followed the start of bud swelling. Temperature seems to be the most important factor controlling the starting date of radial enlargement.

Gevorkiantz, S. R., and N. W. Hosley. 1929. **Form and development of white pine stands in relation to growing space.** Harvard Forest Bul. 13. 83 pp., illus.

Reports on a study that was based on 50 sample plots and detailed measurements on 377 trees. Because of weevil damage and persistent branches, white pine should be grown in dense stands (2,200 + stems per acre) during early life to produce good lumber. Cubic-foot and board-foot form-class volume tables are included.

Haddow, W. R. 1948. **Distribution and occurrence of white pine *(Pinus strobus* L.) and red pine *(Pinus resinosa* Ait.) at the northern limit of their range in Ontario.** Jour. Arnold Arboretum 29: 217-226, illus.

The distribution of red and white pine is described with reference to a datum line which is the northern boundary of the common occurrence of these species in Ontario. It runs southwest from below Lake Abitibi to Sudbury, then west to Lake Superior, follows the north shore to Black Bay and then northwest and west to the Manitoba border. Red pine occurs farther north than white pine.

Haddow, W. R. 1948. **Checklist of stations for white pine and red pine at the northern limit of their range in Ontario.** Ontario Dept. Lands and Forests, 32 pp.

A supplement to the report cited above. Source of the information and remarks concerning the stands at each station are included.

Hastings, George T. 1900. **When increase in thickness begins in our trees.** Plant World 3: 113-116.

In white pine and five other species, the course of radial growth was studied at Ithaca, N. Y., in sections of branches and stems taken at weekly intervals during April to June. White pine radial growth began on May 19. The buds were still unopened. Twigs 2 and 3 years old were the first parts of the tree to start growth.

Kienholz, Raymond. 1934. **Leader, needle, cambial, and root growth on certain conifers and their inter-relations.** Bot. Gaz. 96: 73-92, illus.

The 1931 seasonal growth of the terminals, needles, and stems of white pine and red pine sample trees was measured at Keene, N. H. Leader growth began May 13, reached a peak on June 10, and ceased about August 15. Needles elongated at the base, reached maximum elongation on July 15, and ceased growth September 2. Data on cambial growth of both pines were similar. The interrelation between time and growth rates of the various growing regions of pine are discussed.

Kramer, P. J. 1942. **Species differences with respect to water absorption at low soil temperatures.** Amer. Jour. Bot. 29: 828-832.

Study of the effects of gradually cooling the soil on water absorption by certain plants including elm, and red, white, loblolly, and slash pines. Absorption was reduced in all species, but more in loblolly and slash pines, which normally grow in warm soil, than in white and red pine, which normally grow at least part of the year in cold soil. Reduction in water absorption caused by cold soil is of considerable ecological and practical importance because it often produces winter injury.

Kramer, Paul J. 1943. **Amount and duration of growth of various species of tree seedlings.** Plant Physiol. 18: 239-251, illus.

Eleven species of tree seedlings were grown together for 3 years at Durham, N. C., and their height growth was measured at intervals during the growing season. The red and white pine (from New York) had only one-sixth the yearly height growth of loblolly, which was by far the fastest growing conifer.

LaRue, Carl D. 1934. **Root grafting in trees.** Amer. Jour. Bot. 21: 121-126, illus.

Root grafting in white pine was studied in Michigan stump fences. Grafts were seen in every stump examined. Removal of the bark at the point of contact by friction is not necessary to produce root grafts.

Lownes, Albert E. 1935. **The King's pine.** Amer. Bot. 41: 17-19.

Describes a large white pine near Hiram, Maine, and various other white pines that had been reserved in Colonial days by royal marking.

Lutz, H. J. 1939. **Layering in eastern white pine.** Bot. Gaz. 101: 505-507, illus.

Reports an instance of layering at Keene, N. H. A low branch on the south side of the mother tree became covered with eroded mineral soil and organic material. The branch developed an independent root system and assumed an upright habit at the point of rooting. The upright branch was 2.4 meters tall and the roots had a horizontal spread of 1.8 meters.

Lyon, N. F. 1951. **Seed dispersal test.** Ont. Dept. Lands and Forests Proj. Rpt. 1950-51: 75-76.

Seed traps placed around two white pine trees caught 2,000 and 3,652 seeds per acre. Seed traveled at least 200 feet. It was dispersed October 3-30.

Morey, H. F. 1935. **The average date of maturity of white pine *(Pinus strobus* L.) seed.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 22, 1 p., illus.

Maturity dates of white pine seed ranged from August 1 in northern Connecticut to September 15 in Vermont, New Hampshire, and southern Maine. Based on observations over a 5-year period.

Munns, E. N. 1938. **The distribution of important forest trees of the United States.** U. S. Dept. Agr. Misc. Pub. 287, 176 pp., illus.

Map shows botanical range of northern white pine as extending from southeastern Manitoba, northern and eastern Minnesota, eastward to the Atlantic Coast and Newfoundland. The area is roughly rectangular except for a southern extension that includes northeastern Ohio, all of Pennsylvania, and continues south to Georgia along the Appalachian Mountains.

Page, Frederick S. 1927. **Living stumps.** Jour. Forestry 25. 687-690.

Living hemlock and white pine stumps were reported from Hanover, N. H., and living hemlock stumps from Ithaca, N. Y. On the larger living stumps in a thinned stand of white pine at Hanover, root grafts were easily found. The living stumps had large numbers of living rootlets, which, linked by root grafts to living trees, may have been a factor in increasing the rate of tree growth after thinning.

Paul, Benson H. 1938. **Knots in second-growth pine and the desirability of pruning.** U. S. Dept. Agr. Misc. Pub. 307, 35 pp., illus.

Branch persistance and the value of pruning were studied in six eastern pine species. Complete natural pruning was slowest in white pine. In plantations, little or no clear lumber could be expected in rotations of less than 80 years. Even in fully-stocked stands, artificial pruning of white pine is essential for the production of any of the best grades of lumber in a reasonable time.

Reineke, L. H. 1941. **Fruiting of 10-year-old conifers.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 47, 3 pp.

A comparison of cone production on 10-year-old planted white spruce, red pine, and white pine trees. Cone production on all three species was related to height growth. Trees less than 3 feet high generally did not produce cones. Number of cones varied according to height growth.

Righter, F. I. 1939. **Early flower production among the pines.** Jour. Forestry 37: 935-938, illus.

Average minimum age of flowering among 55 species and varieties of pine was 5.2 years for ovulate flowers and 4.4 years for pollen production, at Placerville, Calif. The minimum record there for white pine was 5 years for ovulate flowers; no record for staminate flowers.

Sinnott, Edmund W. 1952. **Reaction wood and the regulation of tree form.** Amer. Jour. Bot. 39: 69-78, illus.

Using white pines 5 to 10 years old and branches from older trees, the author repeated and extended experiments by Hartmann on the formation and function of compression wood. Main axes and lateral branches were tied into a series of positions different from their natural ones and the distribution of reaction wood after 1 or 2 years of growth was diagrammed from sections.

Stevens, Clark-Leavitt. 1931. **Root growth of white pine.** Yale Univ. School Forestry Bul. 32. 62 pp., illus.

In spring and fall, root growth was rapid. In mid-summer, when height growth was almost complete, the more vigorous roots grew at a slower rate; the less vigorous roots ceased growth altogether. From November 15 to April 1 roots normally did not grow, but greenhouse experiments gave no evidence that the winter rest period was inherited or necessary. Rate of root growth was highly variable but did not appear to be correlated with weather or with the amount of top growth.

Svenson, H. K. 1925. **The white pine in middle Tennessee.** Rhodora 27: 27-28.

The presence of about a dozen full-grown white pines at the summit of a high bluff in the hills west of Nashville is reported. This new station extends the known distribution of white pine some distance to the southwest.

Tarbox, E. E., and P. M. Reed. 1924. **Quality and growth of white pine as influenced by density, site and associated species.** Harvard Forest Bul. 7, 30 pp., illus.

The relationship of lumber quality — based on knot size and current leader growth — to stand density and associated species influencing pine development was studied in 20- to 90-year-old stands of pure pine, pine-hemlock and pine-hardwoods on site I and II on or near the Harvard Forest. Density had little or no effect on height or leader growth but was inversely correlated with knot size in the first 12-foot log. For a given site, lumber quality is determined by knot size, which varies with the years of open growth before crown closure. Thus dense and uniform pine reproduction is desirable.

Toumey, James W. 1929. **Some observations on the importance of early dominance in pure stands of white and red pine in New Hampshire.** Mich. Agr. 8 (8): 5, 21.

Early expression of dominance in pure red and white pine stands prevents stagnation that would require costly early thinnings; as a result, some trees will have two or three times as much volume as the average tree in the stand as well as good form and quality. Dominance is better expressed in natural stands than in plantations. Seeds and seedlings should not be sorted into grades in the nursery because this reduces the ability of trees in the resulting stands to express dominance.

Weck, H. 1944. **Kronenausmasse and Zuwachsleistung.** Forstarchiv. 20: 73-78.

Results of growth studies of several conifer species growing under a variety of conditions (including white pine in strictly even-aged stands of several ages). Crown-surface area, expressed as the product of crown length and maximum width, was correlated with basal-area increment, but less so in even-aged than in irregular stands.

Wheeler, C. F. 1898. **A sketch of the original distribution of white pine in the Lower Peninsula of Michigan.** Mich. Agr. Expt. Sta. Bul. 162: 5-6, illus.

Eastern white pine was originally found throughout the Lower Peninsula, but the southern limit of white pine logging is sketched on a map as beginning on Lake Michigan near the southern boundary of Van Buren County and extending northeastward into northern Gratiot County, thence turning south of east and terminating on the Lake Huron shore in central Saint Claire County.

Wojczynski, Wladyslaw. 1932. **Proba ustalenia zaleznosci przyrostu od zwarcoa dla kedmek klasy biologicznej w drzewostanie sosnowyn. (Relation between growth and stand density for a biological tree class in pine stands.)** Roczniki Nauk Rolnicz i Lesnych (Polish Agr. and Forest. Ann.) 27 (2): 227-262, illus.

Subdominant white pine trees were investigated. The author concludes that average radial distance can be used as a measure of stand density instead of the more expensive crown-projection method, and the comparatively easy sample-tree method can be substituted for the sample-plot method to determine degree of stocking as a guide in management.

Wright, Jonathan W. 1953. **Notes on flowering and fruiting of northeastern trees.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 60, 38 pp.

For specimen trees of white pine and other species in the Philadelphia area, the author recorded the position in the crown and on branches of the female and male flowers, tree height at first appreciable flowering, the degree of maleness and femaleness of young and older trees, and dates of pollen-shedding and female-cone receptivity. Self-pollination is possible in white pine. White pine tends to produce flowers and fruit year after year, but cone weevils cause heavy losses of the developing cones and are the chief cause of seed-crop periodicity.

ATMOSPHERIC AND BIOTIC RELATIONS (including fire)

Adams, W. R. 1935. **Studies in tolerance of New England forest trees. XII. Effect of thinning in plantations on some of the physical factors of the site and on the development of young northern white pine and Scotch pine (*Pinus silvestris* L.).** Vt. Agr. Expt. Sta. Bul. 390, 147 pp., illus.

Detailed results from removal of 45% of basal area in a 20-year-old white pine plantation. Trees of largest diameter and best form showed an increase in diameter growth and total volume production but no change in quality of wood, as indicated by specific gravity. Conditions continued beneficial to tree growth 4 years after treatment.

Baker, F. S. 1949. **A revised tolerance table.** Jour. Forestry 47: 179-181.

In a canvass of American foresters on the question of the tolerance of American timber species, 72% of 55 respondents expressed opinions that eastern white pine is intermediate in tolerance.

Bartholomew, W. V., and A. G. Norman. 1947. **The threshold moisture content for active decomposition of some mature plant materials.** Soil Sci. Soc. Amer. Proc. 11: 270-279.

Alfalfa, Sudan grass, oat straw, hemp bark, and white pine needles were studied. The moisture content at which decomposition of pine needles began, at temperatures of 25 and 37° C., was 15-17%, and the relative humidity required was 80-86%. Increased temperature shortened the length of time before the peak rate of CO_2 evolution was reached.

Bates, C. G. 1925. **The relative light requirements of some coniferous seedlings.** Jour. Forestry 23: 869-879.

Grown for 11 months under artificial light comparatively rich in the longer wavelengths, the seedlings of eight species survived under very low light intensities. White pine survived in less than 1% of noon September sunlight. Height of the seedlings was not visibly affected by the light intensity, but root length and branching were markedly reduced in weak light, which suggests that seedlings may succumb to unfavorable soil conditions under low light intensities rather than to failure of photosynthesis.

Bates, C. G., and Jacob Roeser, Jr. 1928. **Light intensities required for growth of coniferous seedlings.** Amer. Jour. Bot. 15: 185-194, illus.

White pine was among 12 species in this test of survival and growth under artificial light with an intensity of less than 1% to more than 18% of full sunlight. Poor germination and low survival made the number of surviving white pine seedlings too few for conclusive results, but the theoretical minimum light in which growth could be made was set at 2% — lower than other pines but nearly four times the minimum for redwood and nearly twice the minimum for Douglas-fir. The pines appear to be rather inefficient photosynthetically.

Burns, George P. 1915. **The relative transpiration of white pine seedlings.** Plant World 18: 1-6.

As determined through measurements of evaporation from a black atmometer, seasonal transpiration of first-year white pine seedlings grown in a nursery bed was 21 times greater under no shade and 8 times greater under half shade, than when the seedlings were grown under full shade. Study data indicate that size of plant must be related to photosynthesis and assimilation rather than absorption and transpiration of water.

Burns, George P. 1923. **Studies in tolerance of New England forest trees. IV. Minimum light requirement referred to a definite standard.** Vt. Agr. Expt. Sta. Bul. 235, 32 pp., illus.

Minimum light requirements of a number of species was determined by measuremen of the amount of CO_2 given off in respiration at different light intensities. Easter white pine required a minimum of 10.4 milliamperes, compared to 28.7 for Scotch pine, 13.3 for red oak, 8.7 for Norway spruce, 8.4 for hemlock, 7.5 for beech, and only 3.4 for sugar maple.

Candy, R. H. 1939. **Discussion on the reproduction and development of white pine.** Forestry Chron. 15: 88-92.

White pine has disappeared from many parts of central and eastern Canada because of natural agencies such as invasion of spruce and fir from the north and tolerant hardwoods from the south, as well as current logging practices. Present stands are restricted mostly to dry, sandy, or gravelly soils where the species can be reproduced successfully with the aid of prescribed fire for seedbed preparation.

Cary, Austin. 1936. **White pine and fire.** Jour. Forestry 34: 62-65.

The author observed that a large part of the pine originally found in Maine started following fire, and that without fire it has seldom reproduced itself in the natural state because of competition from the more tolerant species. On sandy soils pine will usually reproduce itself without help, and on the medium soils the new stand may be thrown into pine with a little management; but on the loamy soils the hardwoods will inevitably follow pine unless the area is pastured, plowed, or burned.

Christensen, Clyde M., and A. C. Hodson. 1954. **Artificially induced senescense of forest trees.** Jour. Forestry 52: 126-129.

Fifteen white pine trees (25 to 35 years old) were tightly banded 4 to 5 feet above ground with 1-inch wide steel bands. Describes damage, death, and subsequent invasion by diseases and insects.

Conover, David F. 1953. **Effects of competition on red pine and white pine reproduction.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 392. 2 pp.

Competition from brush and heavy overstory seriously retard growth and abundance of red pine seedlings, while under the same conditions white pine seedlings often continue to grow and increase.

Eyre, F. H. 1933. **Aspen competition in Norway pine plantations.** Jour. Forestry 31: 318-321.

White pine will usually have a better survival rate than red pine in competition with aspen but the white pines will be smaller. Systematic care by periodic weedings and release cuttings is the only way to insure success of pine plantations where aspen is present.

Gast, P. R. 1930. **A thermo-electric radiometer for silvical research with preliminary results on the relation of insolation to the growth of white pine.** Harvard Forest Bul. 14, 76 pp., illus.

The apparatus, which gives a better record than any other method previously used, is described. Radiation that is 27% of radiation in the open is the minimum for white pine survival. Leader growth is proportional to radiation, as measured by the thermopile, up to the intensity of full solar radiation.

Grasovky, Amihud. 1929. **Some aspects of light in the forest.** Yale Univ. School Forestry Bul. 23, 53 pp., illus.

Discusses the physiological effects of solar radiation on plants, the measurement of light in silvical studies, and some concepts of the effect of light on forest vegetation. Experimental pot cultures of white pine and other species studied over a 10-month period under various light intensities and ranges of the visible spectrum demonstrated that at 300 foot-candles all plants survived and grew regardless of light quality but at 65 foot-candles all were dead or dying.

Henry, Alfred J. 1902. **The climate of the white pine belt.** Forestry and Irrig. 8: 419-423.

Climate of the Lake States pine belt is described from weather records. It seems probable that occurrence of pine should be ascribed to a fortunate combination of soil and climate. The dominating climatic characteristics are: (1) an atmosphere that contains a high percentage of moisture, with much cloudiness and little bright sunshine; (2) frequent precipitation uniformly distributed throughout the year; and (3) relatively low temperature, and no hot winds or prolonged periods of high temperature.

Hutchinson, A. H. 1918. **Limiting factors in relation to specific ranges of tolerance of forest trees.** Bot. Gaz. 66: 465-493.

Records of exploration and personal knowledge of the forests of Ontario are the basis for this discussion of limiting site factors and the role of competition in the forest succession. White pine is held to be a pioneer species with relatively limited range of tolerance to shade, moisture, and temperature. Light is the limiting factor in the competition of white pine with hemlock and maple.

Lyon, Charles J. 1940. **Tree growth beside a rain gauge and thermometer.** Ecology 21: 425-437.

Yearly deviaions of secondary growth for nine white pines and trees of other species were compared with rainfall and mean daily temperature for certain parts of the year over a period of 70 years. Significant correlation coefficients of growth with rainfall throughout the growing season and with March and April mean daily temperatures were obtained.

Lyon, Charles J. 1943. **Water supply and the growth rates of conifers around Boston.** Ecology 24: 329-344.

Comparison of growth rates with the rainfall records for nearby weather stations brought out the importance for rainfall during the growing season. There was also some evidence of lag and cumulative effects from previous seasons and a general demonstration that fluctuations in growth rates from year to year reflect variations in water supplied through the soil.

Maissurow, D. K. 1935. **Fire as a necessary factor in the perpetuation of white pine.** Jour. Forestry 33: 373-378.

White pine in both virgin and cut-over land in southwest Pontiac County, Quebec, originated following fire. Fire is not recommended as a tool, but cutting methods should be aimed to reproduce fire conditions. Erosion, inundation, and windthrow were other factors that permitted white pine to come in.

Mayall, K. M. 1941. **White pine succession as influenced by fire.** Natl. Res. Council Canada Interim Rpt. 989. 29 pp., illus.

A survey of seven widely scattered areas in the Ottawa Valley Region revealed that white pine regeneration on cut-over and burned-over lands is insufficient for future requirements, and that in the tolerant hardwood cover type white pine is no longer significant. Burning in stands of mature timber stimulates regeneration but the results of fire in young stands are doubtful.

Minckler, Leon S. 1939. **Transpiration of trees and forest.** Jour. Forestry 37: 336-339.

Direct measurements of transpiration were made on samples from several white pines and on some northern hardwoods *in situ.* Mean annual rainfall was 40 inches. The average seasonal transpiration per tree and for a hypothetical pure forest of each species were calculated. Species make-up, the amount of foliage, the foliage exposure, soil-moisture, and the atmospheric humidity level are the important factors in comparing water losses from different forests.

Mitchell, H. L. 1936. **The effect of varied solar radiation upon the growth, development, and nutrient content of white pine seedlings grown under nursery conditions.** Black Rock Forest Papers 1 (4): 15-22.

Experimental evidence indicates that the largest (total dry weight) white pine seedlings are grown under conditions of full light in temperate humid regions. Young seedlings grown in low light intensities are taller and have more and longer needles than those exposed to higher light intensities, but they are light, spindly, and succulent and have poorly developed roots.

Mitchell, H. L., and R. O. Rosendahl. 1939. **The relationship between cumulative solar radiation and the dry weight increase of nursery-grown white pine and red pine seedlings.** Black Rock Forest Papers 1 (13): 88-93.

Experiments indicate that for white pine and red pine there is an arithmetic/logarithmic correlation between seedling yields and cumulative solar radiation. This relationship, which takes the form of a linear proportion, is valid under certain conditions of mineral nutrition, and when the radiant-energy measurement used is that of total radiation. Seedlings exposed to full sunlight during the greater part of the growing season are not only heavier (total dry weight) but have better root systems and a more favorable root/shoot ratio than plants grown in lower light intensities.

Motley, J. A. 1949. **Correlation of elongation in white and red pine with rainfall.** Butler Univ. Bot. Studies 9: 1-8.

Measurements of annual elongation were taken of the main stems and secondary branches of 100 white pines and 50 red pines in Indiana. Curves of growth were plotted for both main and secondary stems, and composite curves were made for each of these. Rainfall data were collected, and curves were plotted for various combinations of months. Elongation in white pine showed closest correlation with rainfall of the storage season (May-November) of the preceding calendar year. This was true of both primary and secondary axes.

Perry, George S. 1932. **Some tree antagonisms.** Pa. Acad. Sci. Proc. 6: 136-141.

When white pine grows in association with black walnut and black locust, the pine becomes unthrifty and finally dies. Walnut is known to excrete root toxins that are inimical to many kinds of vegetation, and black locust may do the same. But association with red maple and other hardwoods seems to benefit white pine.

Shirley, Hardy L. 1936. **Lethal high temperatures for conifers and the cooling effect of transpiration.** Jour. Agr. Res. 53: 239-258.

The ability of white pine, red pine, jack pine, and white spruce to withstand high temperatures was tested in the laboratory. There was little difference among them. Resistance increased with increasing age and with size or mass of plant or tissue; tops were more resistant than roots. White pine and white spruce were able to rcover from heat injury by sending out epicormic shoots but the other species were inferior in this respect.

Shirley, H. L. 1943. **Is tolerance the capacity to endure shade?** Jour. Forestry 41: 339-345.

Reviews history of 90-year-old concept of tree tolerance and its many modifications. Includes an evaluation of the Lake States studies (1929-38) of seedling jack, red, and white pine, and white spruce that were exposed to various degrees of natural and artificial shade, drought, heat, root competition, and nutrient deficiencies. The author found that survival and rank in successional series depended primarily on shade tolerance, but that this was not necessarily related to the other environmental deficiencies.

Shirley, Hardy, L. 1945. **Reproduction of upland conifers in the Lake States as affected by root competition and light.** Amer. Midland Nat. 33: 537-612, illus.

Experiments on the reaction of jack pine, red pine, white pine, and white spruce to various light and moisture conditions in the nursery and under aspen and jack pine stands were followed by surveys of light conditions and natural reproduction in aspen, jack pine, and red pine stands. For all species tested, at least 20% but less than 43% light was necessary for satisfactory establishment and growth in the nursery. Either shade or root competition may be limiting factors in the growth of young conifers.

Toumey, J. W. 1919. **Relation of gray birch to white pine.** Jour. Forestry 17: 15-20.

Competition between birch and pine of about the same age was studied on a series of temporary plots on or adjacent to a sand plain near Keene, N. H. The birch was not dense enough to kill the pine, but pine height growth decreased with increasing density of the birch overstory. The principal competition was for soil moisture and nutrients rather than for light. White pine understories can be released by cutting birch for fuelwood as markets and rate of growth dictate.

Toumey, James W., and Earnest J. Neethling. 1924. **Insolation a factor in the natural regeneration of certain conifers.** Yale Univ. School Forestry Bul. 11. 63 pp.

Data from nine variously treated plots under full or partial sunlight indicate that nearly all first-year mortality of white pine, hemlock, and white spruce seedlings was caused by heat lesions formed at ground line by high soil temperature. This type of mortality took place even though the roots of the seedlings remained in the zone of available moisture.

Wood, O. M. 1932. **An example of white pine reproduction on burned lands in northeastern Pennsylvania.** Jour. Forestry 30: 838-845, illus.

From a group of 11 white pines that had survived logging and subsequent fires, study strips were run in the four cardinal directions. Amount of white pine reproduction was less at greater distances from the seed trees and was greatest on the east and north strips, least on the west strip (prevailing wind was from the southwest). Establishment of reproduction was greatest 7 to 9 years after the last fire and declined steadily since then.

Wyman, Donald. 1950. **Killing woody plants with chemicals.** Arnoldia 10: 70.

Several white pines 35 feet tall died within 3 weeks after poison ivy under them had been sprayed with ammate in early spring.

EDAPHIC RELATIONS

Adams, W. R. 1934. **Studies in tolerance of New England forest trees. XI. The influence of soil temperature on the germination and development of white pine seedlings.** Vt. Agr. Expt. Sta. Bul. 379, 18 pp., illus.

Report on a greenhouse study of white pine germination, survival, and first-year growth in sandy loam soils with ample moisture held at four constant soil temperatures (bracketing the natural range of soil temperature). Results are discussed in relation to white pine silviculture.

Aikman, J. M. 1945. **Response of pine seedlings to site selection on eroded soils.** Iowa Acad. Sci. Proc. 52: 77-82.

On Lindley loam soils eroded of all but 1 foot of the B horizon, white pine 5 years after planting showed better height growth but slower diameter growth and less crown volume than red pine.

Alway, F. J., Joseph Kittredge, and W. Methley. 1933. **Composition of the forest floor layers under different forest types on the same soil type.** Soil Sci. 36: 387-398.

Study on Star Island, Minn., showed in all forest types an increase in ash, lime, and nitrogen, and a decrease in acidity on passing from the litter, through the duff, to the leafmold. All values for material from the white pine stand were intermediate, but were closer to those of the other pines than to those of hardwoods. White and red pine leaves are similar in composition.

Alway, F. J., W. J. Methley, and O. R. Younge. 1933. **Distribution of volatile matter, lime, and nitrogen among litter, duff, and leaf mold under different forest types.** Soil Sci. 36: 399-407, illus.

By laboratory analysis of 25 representative 1-square-foot samples from each of four forest types (jack pine, red pine, white pine, and maple-basswood) on Starr Island, Minn., the distribution of dry matter and some of its fractions in pounds per acre between the L, F, and H organic layers, the upper 2.75 inches of mineral soil, and the undergrowth that occurred on the samples, was determined. The greatest weight of organic matter occurred under the white pine type as did the greatest weight of volatile matter.

Asahi, Masami. 1953. **An edaphological study on growth of white pine.** Tokyo Univ. Forests Bul. 45: 103-110, illus.

Studies in the Tokyo University Forest in Hokkaido led to the conclusion that the growth of white pine is affected by the properties of the deeper layers of soils as well as the upper layers because its roots penetrate deeply. Among soils of different physical properties, all except excessively clayey soil seem favorable for growth. Experiments with potted seedlings showed that 25% calcium saturation is the optimum and 80% the upper limit for growth.

Auten, John T. 1945. **Relative influence of sassafras, black locust, and pines upon old-field soils.** Jour. Forestry 43: 441-446.

Analysis of soil samples from natural stands of sassafras and black locust and from pine plantations indicates that these species are all useful in preparing old-field sites for native hardwoods. The pines have economic value themselves and can prepare the site for the eventual succession of native hardwoods on the temporarily deplated soils of the region.

Burns, George P. 1944. **Soil temperature as influenced by the density of white pine cover.** Vt. Agr. Expt. Sta. Bul. 513, 35 pp.

Records of average soil temperature over a 10-year period and detailed records for a sample year are presented for thinned and unthinned white pine stands and a station on bare ground. Temperatures are variable but show some unexpected relationships with forest cover; most of these can be explained in terms of season, depth of snowfall, and snow melt. It is emphasized that average temperatures are of little use when studying tree growth.

Chandler, Robert F., Jr. 1943. **Amount and mineral content of freshly fallen needle litter of some northeastern conifers.** Soil Sci. Soc. Amer. Proc. 8: 409-411.

Analysis of samples of eastern white pine litter from a plantation near Ithaca, N. Y., and a natural stand in the Adirondacks yielded nutrient contents of 0.60% Ca, about 0.19% Mg, 0.18% K, 0.06% P, and about 10.7% N. Annual white pine litter deposition was 2,700 pounds per acre and nutrient returned to the soil was (in pounds) about 16 Ca, 5 K, 2 P, and 29 N.

Craib, Ian J. 1929. **Some aspects of soil moisture in the forest.** Yale Univ. School Forestry Bul. 25, 62 pp., illus.

Compares moisture and related physical characteristics of soil supporting a white pine stand with those of an adjacent nonforested soil. Effect of trenching (cutting roots) on soil moisture under white pine stands is described.

Doak, K. D. 1934. **Cortical parasitism of conifer-seedling roots in pure culture by mycorrhizal and non-mycorrhizal fungi.** (Abs.) Phytopath. 24: 6-7.

A fungus resembling *Rhizoctonia silvestria* Melin formed the mantle and Hartig network characteristic of ectotrophic mycorrhizae on white pine and other conifers and also infected the cortex of mother roots. Two physiologic strains of *Armillaria mellea* grown with white pine infected the cortices of short roots and mother roots.

Doak, K. D. 1934. **Fungi that produce ectotrophic mycorrhizae of conifers.** (Abs.) Phytopath. 24: 7.

In pure-culture syntheses the following fungi gave typical ectotrophic mycorrhizae on white pine: *Boletus granulatus, Boletinus picitis, Cantharellus cibarius, Amanita muscaria, Russula lepida,* and *Scleroderma vulgare.* The mantle and Hartig' network characterizing this form was demonstrated histologically in each case.

Dosen, R. C., S. F. Peterson, and D. T. Pronin. 1950. **Effect of ground water on the growth of red pine and white pine in central Wisconsin.** Wis. Acad. Sci. Arts and Letters Trans. 40: 79-82, illus.

A site with an impoverished sandy soil on the edge of an artificial lake was planted with red and white pine. After 20 years the height of the trees growing where the water table was about 50 inches deep was more than double that where the water table was about 160 inches deep. The growth effect was due in part to the chemical composition of the ground water.

Ernst, Fritz. 1937. **Wirkungen der einzelnen Hilfspflanzen in den nordostbayerischen Krüppelbaständen.** Forstwiss. Centbl. 59: 50-66, 105-122, 177-192, 217-227, 291-299, illus.

Various trees and shrubs have been used to improve the soil and stand conditions in the scrubby pine forests of northeastern Bavaria. White pine seems to thrive best of all conifers on raw soils, but is shallow-rooted and does not improve the site for *P. silvestris.* Successful establishment of forest on these sites requires soil cultivation and introduction of soil-improving species.

Fisher, R. T. 1928. **Soil changes and silviculture on the Harvard Forest.** Ecology 9: 6-11, illus.

The profile of sandy loam soils under an 80-year-old white pine-hemlock stand and under an adjacent 18-year-old hardwood stand that had succeeded a similar softwood stand are described. Under the softwoods there was an accumulation of 3 inches of litter and mor humus over a ¾-inch leached horizon and ½-inch horizon of illuviation. Under the hardwoods there was ¼-inch of litter and mull humus over 3 inches of A horizon in which there was no leached horizon. This evidence of soil change, together with the strong natural succession to hardwoods, were the basis for recommending that mixed pine-hardwood stands be favored.

Fraser, Donald A. 1954. **Ecological studies of forest trees at Chalk River, Ontario, Canada. I. Tree species in relation to soil moisture sites.** Ecology 35: 406-414, illus.

Relationships between soil moisture and species distribution. White pine is primarily associated with the dry sites.

Garin, George Illichevsky. 1942. **Distribution of roots of certain tree species in two Connecticut soils.** Conn. Agr. Expt. Sta. Bul. 454, 167 pp., illus.

Results from a detailed study made in 7-year-old pure and mixed plantations on Merrimac loamy sand and Charlton fine sandy loam soils. White pine had the greatest number of roots of all sizes. There was a short, stubby tap root, with small roots forming a heavy mass around the root crown. Silvicultural implications are discussed.

Garstka, Walter Urban. 1932. **The calcium content of Connecticut forest litter.** Jour. Forestry 30: 396-405.

Study indicates a correlation between Connecticut forest associations in their trend toward the climax and the calcium content of their litter. Total calcium content increased with the advance of the forest types towards the climax (hemlock-hardwoods) up to the oak-hickory-hardwoods types, after which it showed a slight decrease.

Gast, P. R. 1937. **Contrasts between the soil profiles developed under pines and hardwoods.** Jour. Forestry 15: 11-16.

A brief review of literature and of studies at the Harvard Forest on the influence of land-use history and earthworm activity on the development of soil profiles.

Gast, P. R. 1937. **Studies on the development of conifers in raw humus. III. The growth of scots pine (*Pinus sylvestris* L.) seedlings in pot cultures of different soils under varied radiation intensities.** Statens Skogsförsöksanst. [Sweden] Meddel. 29: 587-682, illus.

Radiation, nitrogen nutrition, and potassium nutrition were varied simultaneously in pot cultures of white pine. Dry weights of the plants increased rapidly with increases in nitrogen concentration from 50 to 100 ppm. and much more slowly up to 250 ppm. The whole series of experiments reported show that the effect of nitrogen supply is always dominated by the level of radiation intensity.

Goldthwait, Lawrence, and Charles J. Lyon. 1937. **Secondary growth in white pine in relation to its water supply.** Ecology 18: 406-415.

In central New Hampshire and Vermont total precipitation absorbed by the soil during the season for secondary growth (normally May to July) is the dominant element in the complex of climatic factors affecting the width of annual rings.

Griffith, B. G., E. W. Hartwell, and T. E. Shaw. 1930. **The evolution of soils as affected by the old field white pine-mixed hardwood succession in central New England.** Harvard Forest Bul. 15, 82 pp., illus.

Data on profile development, organic matter and nitrogen content, buffer content, pH, texture, tilth, and fauna of the soil were collected in old-field white pine stands up to 80 years old, in succeeding hardwood stands up to 40 years old, and in a virgin forest area. It was concluded that in all major respects the quality of the soil for forest growth is deteriorated by old-field pine stands and is improved by second-growth hardwood stands.

Hatch, Alden B. 1936. **The role of mycorrhizae in afforestation.** Jour. Forestry 34: 22-29.

Growth of white pine seedlings in sandy prairie soil from Wyoming resulted in obvious starvation, but when these soils were inoculated with several mycorrhizal fungi there was a marked increase in absorption of nitrogen, potassium, and phosphorus.

Hatch, A. B. 1937. **The physical basis of mycotrophy in *Pinus*.** Black Rock Forest Bul. 6, 168 pp., illus.

Critical review of the literature and a series of experiments with white and other pines has led the author to conclude that the mycotrophic relationship in pine is a symbiotic one that increases the absorption of soil nutrients. The greater absorption capacity of mycorrhizal seedlings is caused by, and is proportional to, increases in the effective absorbing surface area of short roots. The magnitude of the surface area of short roots, and the relative importance of mycorrhizae in tree nutrition, is determined by the availability of soil nutrients.

Hatch, A. B., and C. Talbott Hatch. 1933. **Some hymenomycetes forming ectotrophic mycorrhizae with *Pinus strobus* L.** Arnold Arboretum Jour. 14: 324-334, illus.

In pure cultures with white pines, typical ectotrophic mycorrhizae were formed by 12 fungi. The mycorrhizal relationship of three of them was not previously known. Methods of study are described.

Hwang, Y. 1938. **Field experiments on nitrogenous decomposition and acidity changes in decaying forest litter.** Forstwiss. Centbl. 60: 661-676.

Experiments were made near Munich on the decomposition of litter of white and jack pines and of several hardwood species. In the pine litter there was an absolute increase in nitrogen after decomposition. Mobilization of nitrogen was much slower than in the hardwood litter. A correlation was found between the initial pH of the litter, the pH of the underlying soil, and that of the decomposed material. Pine litter had an acid buffer-effect except on a very acid soil, when a basic buffer-effect appeared. Mixture of hardwood with pine litter aided the decomposition of the latter.

Li, Tsi-Tung. 1926. **Soil temperature as influenced by forest cover.** Yale Univ. School Forestry Bul. 18, 92 pp., illus.

Influence of young and old white pine stands and grass stands on soil temperature at various depths was studied from July to October at Keene, N. H. Both forest and grass cover modified soil temperatures, particularly by reducing extreme daily fluctuations. Forest cover was more effective than grass but there was little difference in the effect of young and old forest. The effects were more evident in the upper layers of soil than in the lower layers.

Lunt, Herbert A. 1948. **Soil properties and tree growth.** *In* **The forest soils of Connecticut.** Conn. Agr. Expt. Sta. Bul. 523: 71-73.

A 1942 planting of white pine and Norway spruce at Windsor, Conn., had striking growth differences due to differences in soil texture. Merrimac loamy sand and Manchester sandy loam with more than average moisture were compared. By 1947 the pine had grown 17% more and the spruce 70% more in height on the loam than on the sand.

Lunt, Herbert A. 1951. **Effect of slash mulch and slash burn on pine and spruce plantings.** Conn. Agr. Expt. Sta. Bul. 548, 21 pp., illus.

Survival of white pine was unaffected by treatment but growth was increased about 13% in a 6-year period of application of white pine slash mulch. Burning the slash increased growth more. Soil analyses show that slash mulch increased the available potassium and total soluble salts and that burning of the slash increased it more. Presence of slash favored ammonification and slash burning increased phosphorus slightly.

Lunt, Herbert A. 1951. **Liming and twenty years of litter raking and burning under red (and white) pine.** Soil Sci. Soc. Amer. Proc. 15: 381-390, illus.

Parallel series of 1/40-acre plots in red pine and white pine plantations were used to compare the effect on soil properties and tree growth of annual litter raking, annual litter burning, and undisturbed litter — with and without addition of lime. The white pine plots were destroyed after 9 years but showed some effects of treatment on soil pH and soil nitrogen.

Lutz, H. J. 1945. **Vegetation on a trenched plot twenty-one years after establishment.** Ecology 26: 200-202.

The white pine on the plot in 1930 (Toumey and Kienholz, 1931) was all gone in 1943, but the hemlock thrived and increased slightly in numbers. The conclusion: radiation was too low for the relatively shade-intolerant white pine but was favorable for the shade-tolerant hemlock. Thus, while the plot illustrates strikingly the importance of root competition, it illustrates with equal force the importance of solar radiation.

Lutz, Harold J., Joseph B. Ely, Jr., and Silas Little, Jr. 1937. **The influence of soil profile horizons on root distribution of white pine (*Pinus strobus* L.).** Yale Univ. School Forestry Bul. 44, 57 pp., illus.

Seventeen profiles of gray-brown podzolic soils under pure even-aged white pine stands 35-45 years old were examined. The concentration of roots in the upper horizons appears to result from a combination of factors: (1) greater content of fine soil material; (2) generally better physical conditions, particularly structure and consistency; (3) higher moisture equivalent values; (4) higher content of organic matter; (5) higher content of total nitrogen; and (6) higher total exchange capacity and higher content of exchangeable bases.

Lyford, W. H. 1941. **Mineral composition of freshly fallen white pine and red maple leaves.** N.H. Agr. Expt. Sta. Tech. Bul. 77, 12 pp.

Red maple and white pine leaves were collected from several sites on the same soil type (Gloucester sandy loam) and ash analyses were made. Percentage of ash averaged 6.21 and 2.62 respectively and it was shown that the ash of red maple, as compared with that of white pine, contains a larger proportion of silica and a smaller proportion of calcium.

Lyon, Charles J. 1949. **Secondary growth of white pine in bog and upland.** Ecology 30: 549-552.

White pines growing in a bog subject to rise and fall of water level in response to local rainfall and temperature showed the same sequence of narrow and wide rings during the years of unsuppressed growth as upland trees, probably because they had shallow root systems. For young and suppressed pine there is a negative correlation with upland trees, indicating a deep root system.

McComb, A. L., and John E. Griffith. 1946. **Growth stimulation and phosphorus absorption of mycorrhizal and non-mycorrhizal northern white pine and Douglas-fir seedlings in relation to fertilizer treatments.** Plant Physiol. 21: 11-17, illus.

Grown in Iowa on a sandy loam soil, 2-year-old seedlings of both species made satisfactory growth when the soil was inoculated with coniferous humus containing mycorrhizal fungi; on soil not inoculated but fertilized with phoshorus, only white pine made satisfactory growth. Good growth was associated with high phosphorus absorption.

Mitchell, Harold L. 1934. **Pot culture tests of forest soil-fertility with observations on the effect of varied solar radiation and nutrient supply on the growth and nitrogen content of Scots and white pine seedlings.** Black Rock Forest Bul. 5, 138 pp., illus.

White pine seedlings were tested in nutrient-sand cultures and in cultures of four forest soils — with nutrient supplements — to determine the influence of varied nitrogen supply on dry-weight increase, root-shoot ratio, and internal nitrogen concentration of seedlings grown in full sunlight with other nutrients at near optimum supply. In the nutrient-sand cultures, dry weight increase of seedlings — adjusted for size of seed — was greatest when the nitrogen supply was 300 ppm.

Mitchell, H. L. 1939. **The growth and nutrition of white pine (*Pinus strobus* L.) seedlings in cultures with varying nitrogen, phosphorus, potassium, and calcium, with observations on the relation of seed weight to seedling yield.** Black Rock Forest Bul. 9, 135 pp., illus.

A detailed report and discussion of a series of experiments in which cumulative solar radiation was controlled and the response of seedling (dry-weight increase adjusted for reserve dry-weight of the seed) to varying concentrations of N, P, K, and Ca in the nutrient solution was determined.

Mitchell, H. L., R. F. Finn, and R. O. Rosendahl. 1937. **The relation between mycorrhizae and the growth and nutrient absorption of coniferous seedlings in nursery beds.** Black Rock Forest Papers 1 (10): 58-73.

The beneficial influence of ectotropic mycorrhizae on the growth of red spruce and white pine seedlings is inversely proportional to the mineral nutrition of the soil. In the most fertile soils mycorrhizae have no influence, but in very infertile soils seedlings cannot exist without them.

Mogren, E. W. 1954. **Comparison of growth rate of three species of pine on two soil classes on the Lake Vadnais plantation, Minnesota.** Jour. Forestry 52: 359-360.

Growth of the three native pines on two different soil types was compared. The sites were thought to be similar except for difference in soil texture. Growth was better on the Milaca and Bradford fine sandy loam than on the relatively sterile dry Zimmerman loamy fine sand. The growth differences were all significant.

Moore, Barrington. 1926. **Influence of certain soil and light conditions on the establishment of reproduction in northeastern conifers.** Ecology 7: 191-220, illus.

Report on a study on Mt. Desert Island, Maine, of the influence of humus versus mineral soil, and of shade under a forest canopy versus light in small openings, on the germination and survival of red spruce, white pine, red pine, and white spruce. White pine germination was fair on mineral soil in the open but there was no survival after 2 years.

Plice, Max J. 1934. **Acidity, antacid buffering, and nutrient content of forest litter in relation to humus and soil.** Cornell Univ. Agr. Expt. Sta. Mem. 166, 32 pp., illus.

Part I of this report gives, for the fresh leaf litter of white pine and other common northeastern tree species, the content of lime and other principal bases, antacid buffering, acidity, and total nitrogen content. In Part II studies of the same type on humus and soil under different forest types (one of them white pine) are reported. White pine seems to be intermediate between hemlock and most hardwoods in its effect on humus and soil.

Scott, David R. M. 1952. **Growth of hybrid aspen in pot cultures of the litter of forest plants.** Jour. Forestry 50: 107-108.

Nine types of litter, of which one was white pine litter, were analyzed spectroscopically for elements of known nutritional value (except nitrogen). There appeared to be little correlation between the nutrient content of the litter and the growth of hybrid aspen.

Shear, G. M., and W. D. Stewart. 1934. **Moisture and pH studies of the soil under forest trees.** Ecology 15: 145-153, refs.

Five stations were established, one under each of five species in pure stands. Periodic samples for soil moisture were taken at 1-foot intervals to depths of 7 to 10 feet. Moisture equivalent, wilting coefficient, and pH were determined for each depth; and the depth of the water table was recorded. Comparison of these records showed no period of increased water consumption by white pine.

Thomas, W. D. 1941. **The mycorrhizal fungi and mycorrhizae of four coniferous plantations in the Rhine Valley.** Phytopath. 31: 567-569.

Mycorrhizae were studied on four 1-hectare plots in the Black Forest. Hymenomycetes and mycorrhizae were numerous on only one plot and only on this plot did the white pine and other planted conifers appear healthy or give promise of high yields. On the other three plots the trees showed signs of nitrogen starvation.

Toumey, J. W. 1929. **The vegetation of the forest floor: light versus soil moisture.** Internatl. Cong. Plant Sci. Proc. 1: 575-590, illus.

Effects of light and soil moisture on the germination, survival, and growth of white pine and hemlock seedlings and other vegetation were studied on a series of trenched plots. Litter was removed from parts of some plots. It was concluded that, even at very low light intensities, soil moisture was the limiting factor in the germination and growth of tree seedlings. Heavy litter impeded germination and leaf fall under dense stands smothered most of the young plants.

Toumey, James W., and Raymond Kienholz. 1931. **Trenched plots under forest canopies.** Yale Univ. School Forestry Bul. 30, 31 pp., illus.

In trenched and untrenched plots established under a white pine stand in 1922 a distinct succession of vegetation occurred as illustrated by the increasing abundance, density, and number of species and the gradual change from complete dominance by herbs to increasing dominance by woody species. White pine and hemlock seedlings were present on the trenched plot from the beginning, and they maintained the same abundance throughout the period. There were twice as many pines as hemlocks but the hemlocks grew faster.

Tryon, E. H. 1948. **Effect of charcoal on certain physical, chemical, and biological properties of forest soils.** Ecol. Monog. 18: 81-115, illus.

Crocks of soil and charcoal mixtures were set in a greenhouse and sown with white pine seed. Two soils and two kinds, two sizes, and three rates of charcoal application were involved. Germination of white pine was reduced by charcoal, the extent depending on its size and rate of application. Weight of seedlings was little affected, but height was reduced, the extent depending on the size of the charcoal. Effects on damping-off, mycorrhizae, and physical and chemical soil properties are discussed.

Wherry, E. T. 1922. **Soil acidity preferences of some eastern conifers.** Jour. Forestry 20: 488-496.

The local distribution of 23 species with respect to soil acidity was studied at widely scattered points. White pine was studied from North Carolina to New York. It does not appear to colonize soils of high acidity or rich, black alkaline soils of calcarious regions. It is most abundant in typically intermediate habitats, though it is also found on limestone ledges.

PLANT SOCIOLOGY : COVER TYPES

Alway, F. J., and P. R. McMiller. 1933. **Interrelationship of soil and forest cover on Star Island, Minn.** Soil Sci. 36: 281-294.

Jack pine, Norway pine, white pine, and maple-basswood forest types are found on these sandy soils in practically virgin condition. The soil was examined to a depth of 7 to 12 feet at 40 places where the surface is 15 to 46 feet above the lake surface and only coarse-textured soil was found. Describes characteristics of soil profile, organic and acid content of soil, and the forest floor.

Ashe, W. W. 1922. **Forest types of the Appalachian and White Mountains.** Jour. Elisha J. Mitchell Sci. Soc. 37: 183-198.

A white pine type with three site qualities is recognized in the Appalachians. The type occurs on drained alluvial soils and in valleys within the Alleghenian area of the Transition Life Zone. Listed among the xerophytic associations, the type is briefly described as pure but grading at places into hemlock and chestnut-white oak. It is localized in area, being best developed between altitudes of 500-2,000 feet in Pennsylvania, and 3,000-4,000 feet in Tennessee and North Carolina.

Ayres, H. B., and W. W. Ashe. 1905. **The southern Appalachian forests.** U.S. Geol. Survey Prof. Paper 37, 291 pp.

White pine, an important timber tree throughout the southern Appalachians, is most abundant on northwest slopes between elevations of 1,700 and 4,000 feet. Size, distribution, associates, sites, growing conditions, and uses are discussed. Includes a tabulation of some height and diameter measurements at various ages. Volume of standing timber (by species) is tabulated in board-feet for each of the major drainages.

Baldwin, H. I. 1951. **A remnant of old white pine-hemlock forest in New Hampshire.** Ecology 32: 750-752.

A ¼-acre plot was measured and described in a stand of 150-to-200-year-old trees near Bradford, N. H. The main stand contained an average of 360 trees per acre, 64 of which were white pines with an average diameter of 30 inches. The white pines contained 60% of the total stand volume (115,000 board feet).

Ball, J. Curtis. 1949. **Association of white pine with other forest tree species and *ribes* in the southern Appalachians.** Jour. Forestry 47: 285-291.

White pine is gradually establishing itself on a wide variety of sites both at low and high elevations. The optimum range is between 1,200 and 3,500 feet. White pine reproduces readily and competes favorably with the associated species. Fourteen years of fire protection and blister rust control have materially aided the establishment of white pine.

Bergman, H. F. 1924. **The composition of climax plant formations in Minnesota.** Mich. Acad. Sci. Arts and Letters Papers 3: 51-60.

Analyzes the composition of the three climax associations: pine forest, deciduous forest, and prairie. The numbers of trees by species and diameter classes and the character of the secondary vegetation on nine quadrats in uncut and seven quadrats in lightly-cut pine forest are the basis for the conclusions. White pine and red pine are the climax dominants, more numerous and larger than the associated fir, birch, spruce, and poplar.

Braun, E. Lucy. 1950. **Deciduous forests of eastern North America.** 596 pp., illus. Philadelphia.

Describes the present forest cover and the climax conditions for each of nine forest regions. In the hemlock-white pine-northern hardwoods region, the forest formation in each of the seven physiographic sections recognized is discussed separately.

Bromley, Stanley W. 1935. **The original forest types of southern New England.** Ecol. Monog. 5: 63-89, illus.

Describes the pre-colonial forest in each of the three forest regions of southern New England, primarily from interpretation of early records. In its region, white pine dominated the forest by its size and age rather than by its numbers. The species maintained this position over a long period because of its adaptation to dry sites and its ability to compete well on better sites in openings created by fire or windthrow.

Brown, R. T., and J. T. Curtis. 1952. **The upland conifer-hardwood forests of northern Wisconsin.** Ecol. Monog. 22: 217-234.

Analysis of 116 stands showed great variation in composition as expressed by the two to four leading dominants. However, it was found that all the stands were part of a continum of one great community complex and could be arranged along an environmental gradient from xeric pioneer conditions to mesic climax conditions. The stands in less than pioneer condition were dominated by red pine and white pine, those in intermediate condition by white pine, red oak, and red maple.

Cain, Stanley A. 1940. **The identification of species in fossil pollen of *Pinus* by size-frequency determinations.** Amer. Jour. Bot. 27: 301-308.

The size-frequency curve method for pollen analysis is described. Pollen dimensions for white pine and 11 other pine species are given.

Cain, Stanley A., Louise G. Cain, and George Thomson. 1951. **Fossil pine pollen size-frequencies in Heart Lake sediments, Oakland County, Michigan.** Amer. Jour. Bot. 38: 724-731, illus.

Size-frequency analyses were made of fossil pine pollens at depths of 13 to 21 feet in the sediments, and of modern pollens of pines native to the area. There was sufficient agreement to show that the fossil pollens were from the same species. Studies strongly indicate that during the spruce-fir and pine periods jack and red pine were important elements of the vegetation, and white pine may have been present. During the period of hardwood dominance atfer the pine period was over, white pine became an important element.

Cline, A. C., and S. H. Spurr. 1942. **The virgin upland forest of central New England.** Harvard Forest Bul. 21, 58 pp., illus.

In an examination of 68 remnants of the virgin forest, 7 distinct forest types were found as well as numerous minor variations. Nearly all the important differences can be explained in terms of elevation and aspect of the stands and dates and severity of fire, wind, and other destructive forces. The climatic climax occurs on lower slopes and consists of hemlock, beech, sugar maple, and black birch. The ridge top physiographic climax is a hemlock-white pine association with beech, black birch and red maple as minor elements.

Coker, W. C., and H. R. Totten. 1932. **Notes on extended ranges of plants in North Carolina.** Jour. Elisha J. Mitchell Sci. Soc. 48: 138-140.

Brief note on white pine occurrence in Davie County and the southern edge of Chatham County. One tree in 1921 measured 61 inches in circumference 3 feet above the ground, and small trees and seedlings were plentiful.

Colvin, Walter S., and Walter S. Eisenmenger. 1943. **Relationships of natural vegetation to the water-holding capacity of the soils of New England.** Soil Sci. 55: 433-446, illus.

A study of the relationship between natural vegetation and the water-holding capacity of the soil indicated that certain trees, shrubs and herbs grow in greatest abundance on soils of particular water-holding ranges while many other species, including gray birch, hemlock, red maple, red cedar, and white pine, grow on soils varying widely in their moisture-retaining properties.

Cook, H. O. 1931. **Original forests of Cape Cod.** Jour. Forestry 29: 422-423.

After 300 years of occupancy by the white man, the forests of Cape Cod are composed primarily of the fire-resistant species: pitch pine, bear oak, white oak, and scarlet and black oak. Early records tell little of the original forest except that white pine was once abundant. Two small islands near the mainland that have been protected from fire give evidence of the original forest type. These islands now support stands of white pine, hemlock, beech, soft maple, birch, red oak, and some subsidiary species.

Cooper, William S. 1913. **The climax forest of Isle Royale, Lake Superior, and its development.** Bot. Gaz. 55: 1-44, 115-140, 189-235, illus.

Describes the dominant forest, which is equated with the climax for the island. Traces the plant succession from bare rock to climax and emphasizes the importance of windfall in the dynamics of the forest. White spruce and white pine occur very sparsely on the island, and then as individuals towering over the present forest. Reproduction is sparse or lacking. Neither species is important in the climax forest.

Corson, C. W., J. H. Allison, and E. G. Cheyney. 1929. **Factors controlling forest types on the Cloquet Forest, Minnesota.** Ecology 10: 112-125.

Experiments at the Cloquet station failed to develop a satisfactory method of determining forest types on the basis of topography, air temperatures, soil temperatures, humidity, or evaporation. Classification on the basis of the moisture equivalent of the soil seemed to check fairly well with virgin and second-growth stands, but the method is cumbersome and requires technical skill and expensive apparatus.

Dansereau, Pierre. 1953. **The post-glacial pine period.** Roy. Soc. Canada Trans. Ser. 3 Sec. 5, 47: 23-38, illus.

The consistent post-glacial period of dominance by pine in the vegetation of eastern North America is considered in the light of climatic periods and alternation of periods under two hypotheses: requirements of the species for growth and survival (1) unchanged, (2) changed during the period. Questions are raised concerning ecological interpretations of this period.

Donahue, William H. 1954. **Some plant communities in the Anthracite Region of northeastern Pennsylvania.** Amer. Midland Nat. 51: 203-231, illus.

A quantitative ecological analysis was made of nine forest and two shrub communities in Luzerne County. Such characteristics as species composition, density, frequency, basal area, shrub and herbaceous strata, and soil profiles were studied in each stand. Two communities were representative of the oak-chestnut forest region — scrub oak and white oak-red maple. In the latter, white pine was present. In all communities where white pine was in a subdominant position it showed promise of becoming a dominant element in the stand.

Egler, F. E. 1940. **Berkshire plateau vegetation, Massachusetts.** Ecol. Monog. 10: 145-192.

White pine is found at intermediate elevations (Bray's vegetation zone C). It is mixed with sugar maple, beech, yellow birch, and hemlock. Within this zone the old fields are dominated by gray birch and white pine with about 50 secondary species.

Friesner, Ray C., and J. E. Potzger. 1934. **Climax conditions and ecological status of *Pinus strobus*, *Taxus canadensis*, and *Tsuga canadensis* in the Pine Hills Region of Indiana.** Butler Univ. Bot. Studies 3: 65-83, illus.

Eastern white pine characteristically occurs as an upper fringe species in the belt transitional between the *Tsuga* and deciduous hardwoods of the upland plateaus. It and eastern hemlock are considered relict species of a former climatic climax, both having at one time been climatic dominants, but as the climate changed in post-glacial time they gave way to maple and beech, the present climatic dominants.

Friesner, Ray C., and John E. Potzger. 1936. **Soil moisture and the nature of the *Tsuga* and *Tsuga-Pinus* forest associations in Indiana.** Butler Univ. Bot. Studies 3: 207-209.

Figures of total soil moisture less wilting coefficients at several depths are shown for soils under the associations in question (seedling and mature) and under mature *Fagus-Acer* associations. The fact that available soil moisture is least in the *Tsuga* and *Tsuga-Pinus* associations is interpreted to mean that these associations are pre-climax relicts in Indiana rather than normal constituents of the present climax associations.

Goodlet, John C. 1954. **Vegetation adjacent to the border of the Wisconsin drift in Potter County, Pa.** Harvard Forest Bul. 25: 93 pp., illus.

The study, though primarily of the relation of the drift border to present vegetation, considers the peculiar status of white pine in the county. Before the heavy logging of 1860 to 1900, white pine was abundant. Now it is virtually nonexistent. Present lack of pine results from the removal of the seed source by logging, the unfavorable seedbeds, and the widespread fires that followed logging.

Graham, Samuel A. 1941. **Climax forests of the Upper Peninsula of Michigan.** Ecology 22: 355-362, illus.

Although composed largely of climax species, the mixed hardwood-hemlock forests are not yet in the climatic climax state. It is questionable if that hypothetical state can be reached except occasionally, and for a short time, because of fire, biotic, and climate catastrophies.

Grant, Martin L. 1934. **The climax forest community in Itasca County, Minnesota, and its bearing upon the successional status of the pine community.** Ecology 15: 243-257.

The climax plant community of the county is the balsam fir-basswood association, largely restricted to the heavy clay soils of the gray drift. On the sandy red drift there is an edaphic climax of Norway and white or jack pines, and on peat soils an apparently stable subclimax swamp forest of black spruce and tamarack or white-cedar.

Grayson, John F. 1954. **Evidence of four pine species from fossil pollen in Michigan.** Ecology 35: 327-331, illus.

A size-frequency study of fossil pollen at three depths in the sediments of a pond in Livingston County strongly indicates the presence of jack, red, and white pine there during the pine period. The presence of a fourth pine species at the end of the pine period is also indicated. This may have been shortleaf pine.

Halliday, W. E. D. 1937. **A forest classification for Canada.** Canada Forest Serv. Bul. 89. 50 pp., illus.

Describes the division of Canadian forests into eight regions. For the Great Lakes-St. Lawrence Region, the indicator species are white pine, hemlock, red pine, and yellow birch, sugar maple, red maple, and beech. This is the most complex of the regions because of transitional elements, the history of early settlement, and the relatively wide range of climatic conditions covered. White pine probably reached its maximum development in the Algonquin-Laurentides Section.

Halliday, W. E. D. 1950. **Climate, soils, and forest of Canada.** Forestry Chron. 26: 287-301.

Reviews the climate, geology, and soils of Canada and their relations to forest vegetation, which is the basis for classification into eight distinctive forest regions. The Great Lakes-St. Lawrence Region (see Halliday, 1937) is characterized by extensive stands of white and red pine, although sugar maple is also abundant. Pines and hemlock are the climax species of the region, but they can only share this dominant position with certain hardwoods common to the deciduous forest to the south — the maples, yellow birch, and possibly beech.

Harvey, LeRoy H. 1919. **Some phytogeographical observations in Lake County, Michigan.** Mich. Acad. Sci. Rpt.: 213-217.

The white pine type is considered as an edaphic climax. The traditional climatic climax theory is not sufficient to explain the vegetation complex, as the case of white pine shows.

Harvey, LeRoy H. 1922. **Yellow-white pine formation at Little Manistee, Michigan.** Bot. Gaz. 73: 26-43, illus.

Suggests that the area had been possessed for centuries by a stable pine formation. The few veterans in the stands studied were part of that formation and survived a catastrophe some 200 years earlier. Since that time the original formation has been under gradual replacement with another of the same kind. (Early surveyors and some North Woods lumbermen recorded *Pinus resinosa* as "hard pine" or "yellow pine" about 1800).

Hawley, Ralph C. 1933. **Does northern white pine form a climax type?** Jour. Forestry 31: 866-868.

Detwiler's (1933) interpretation of the ecological position of white pine is disputed. The northern white pine type is not the climax type over any considerable area. It is shown that several authors were quoted out of context to support contrary views. However, the ideas and conclusions of Detwiler regarding the intensive management and protection from blister rust are supported.

Heimburger, Carl C. 1934. **Forest-type studies in the Adirondack region.** Cornell Agr. Expt. Sta. Mem. 165, 122 pp., illus.

The forest lands of the Adirondack Region are classified into biologically equivalent sites on the basis of ground vegetation. The importance of physiographic features is recognized and the 22 types described are grouped into three series that correspond to climatic areas with different floristic provinces. White pine occurs in at least 14 of the vegetation types and is an important element in 9 of them — those that occur on the drier and poorer soils.

Hough, A. F. 1943. **Soil factors and stand history in a virgin forest valley on the northern Allegheny Plateau.** Soil Sci. 56: 19-28, illus.

Studies of stand history and soil characteristics were made in a hemlock-beech, beech-maple, and white pine-hemlock virgin forest in northwestern Pennsylvania. The author concludes that climatic and biotic factors are as important in creating these forest associations as are soil characterisics. However, soil characteristics, especially of the humus horizon, were related to the successional stage of the major forest associations.

Hough, A. F., and R. D. Forbes. 1943. **The ecology and silvics of forests in the high plateaus of Pennsylvania.** Ecol. Monog. 13: 299-320.

In this region there are three major and generally distinct forest associations in the virgin forest: white pine-hemlock, hemlock-beech, and beech-maple. The first is a sub-climax type originating from fire, windthrow, or other catastrophies. Major associates were chestnut, red maple, and oaks. The white pine types, being sub-climax, are especially impermanent and difficult to manage in perpetuity. They occur most frequently on south and west slopes.

Kittredge, Joseph Jr. 1934. **Evidence of the rate of forest succession on Star Island, Minnesota.** Ecology 15: 24-35.

These forests afford excellent examples of the four stages in the succession from jack pine to Norway pine to white pine to sugar maple-basswood. The evidence of the transition between each two stages is exceptionally complete and leaves no doubt that the entire succession would be consummated in a sufficient period of time. The minimum periods of occupation are: jack pine, 100 years; Norway pine, 300 years; white pine, 250 years; a total of at least 650 years before the climax would become dominant.

Lindsey, Alva J. 1932. **Preliminary fossil pollen analysis of the Merrillville, Indiana, white pine bog.** Butler Univ. Bot. Studies 2: 179-182, illus.

The bog consists of three general strata: peat, water, and mud. Pine pollen was found in the top of the mud stratum but mostly in the peat. The order of postglacial succession in this bog area has been Abies-Picea, Picea-Pinus, and Pinus-other genera.

Lindsey, Alva J. 1932. **The Merrillville white pine bog, Lake County, Indiana.** Butler Univ. Bot. Studies 2: 167-178.

The bog is about 40 acres in size and is filled with about 25 feet of peat. A pure white pine stand — the only one in Indiana — occupies about 9 acres in the center of the bog. The bog has not yet reached its climax stage, as attested by the lack of pine seedlings and the presence of oak seedlings. The white pine has neither the density nor the coverage that would be expected of the dominant tree.

Livingston, Burton Edward. 1905. **The relation of soils to natural vegetation in Roscommon and Crawford Counties, Michigan.** Bot. Gaz. 39: 22-41, illus.

Describes the white pine type, one of seven vegetation types in the area. This type occurs on the uplands, specifically on clay hills, moraines, gravelly ridges, and often at swamp margins. It is concluded that soil texture is the main factor determining the distribution of forest types in this area. Of second importance, only because of its limited occurrence, is the nearness of ground water to the soil surface.

Lutz, H. J. 1930. **Original forest composition in northwestern Pennsylvania as indicated by early land survey notes.** Jour. Forestry 28: 1098-1103.

Land-survey notes made in 1814-15 contained nearly 6,000 references to some 32 tree species. Abundance and frequency values calculated indicate that, as a whole, the original forest was composed chiefly of beech, hemlock, maple, birch, white pine, and chestnut. These species made up over 88% of the stand, of which nearly 6% was white pine. The composition was not greatly different from that at Heart's Content.

Lutz, H. J. 1930. **The vegetation of Heart's Content, a virgin forest in northwestern Pennsylvania.** Ecology 11: 1-29.

In this remnant of the original forest of the Allegheny Mountains in northwestern Pennsylvania, two forest communities were recognized: hemlock-beech association covering about 75% of the area and a hemlock consociation covering the remaining 25%. The principal tree species in the first, in their order of abundance, were hemlock, beech, white pine, red maple, chestnut, and black birch. In the second they were hemlock, white pine, yellow birch, and beech. White pine appears to be dying out in both of these communities; reproduction of the species is practically absent.

Lutz, H. J. 1934. **Additions to the flora of Heart's Content, a virgin forest in Northwestern Pennsylvania.** Ecology 15: 295-297.
About 60 plant species are added to those given by Lutz above.

Lutz, H. J., and A. L. McComb. 1935. **Origin of white pine in virgin forest stands in northwestern Pennsylvania as indicated by stem and basal branch features.** Ecology 16: 252-256.
The pine at Heart's Content is not even-aged as previously thought; but neither is it all-aged because no pines are younger than 175 years. The stand originated under a partial canopy of hardwoods and hemlock and there were only about seven trees per acre. At Ludlow the stand originated under open conditions and came in pure and even-aged as can be read from the features.

McIntosh, R. P. 1951. **Pine stands in southwestern Wisconsin.** Wis. Acad. Sci. Arts and Letters Trans. 40: 243-257, illus.
A study of the flora and site factors of many areas of southwestern Wisconsin and adjacent northwestern Illinois where white pine trees are a conspicuous element of vegetation suggests that these are relict stands of the general southward extension of the northern coniferous forest in glacial times. The trend toward eventual extinction continues.

Maissurow, D. K. 1941. **The role of fire in the perpetuation of virgin forests of northern Wisconsin.** Jour. Forestry 39: 201-207.
Comparative studies were made of the species composition of reproduction, crown classes, and age structure in virgin forest and rehabilitating burns in and around the Nicolet National Forest. Life history of the virgin forest was interpreted. Forest fires in the last five centuries have not been great catastrophies, but periodic and normal ecological events.

Morey, H. F. 1936. **A comparison of two virgin forests in northwestern Pennsylvania.** Ecology 17: 43-55, illus.
Compares the composition and development of Cook Forest and Heart's Content, two virgin forests in northwestern Pennsylvania. Ninety-three species were common to both forests — 91 in Heart's Content alone, and 57 in Cook Forest alone. Heart's Content had a much lower percentage of white pine, a smaller number of trees per acre, and a smaller basal area per acre. There is evidence in both forests that the key species of white pine, oak, and chestnut are being replaced by hemlock and members of the maple-beech association.

Nichols, G. E. 1935. **The hemlock-white pine-northern hardwood region of eastern North America.** Ecology 16: 403-422.
The region centers around the Great Lakes and the St. Lawrence Basin between the northern conifer region and the southern deciduous forest region. The common species are placed in four groups according to their ranges. Through most of its range, white pine is a normal but minor part of the climatic climax, occurring in mixed stands with hemlock and hardwoods.

Potzger, J. E. 1942. **The lake forest of northern Wisconsin and upper Michigan: a phytosociological study.** (Abs.) Ind. Acad. Sci. Proc. 51: 75.
A study was made of 11 forest stands, 9 of hardwoods and 2 of pine. Red pine is more prominent on dry sandy uplands and white pine on moist sites. Red maple constitutes the second-layer tree stratum in the red pine type and balsam fir in the white pine type.

Potzger, J. E. 1946. **Phytosociology of the primeval forest in central northern Wisconsin and a brief postglacial history of the lake forest formation.** Ecol. Monog. 16: 211-250.

A lengthy discussion of existing forest formations and their probable origins. Based on phytosociological survey of 2 pine and 8 hardwood stands and on 25 pollen profiles. Concludes that pine is an edaphic climax in the lake forest but once covered a wide belt east to New Jersey and south to Texas. An extensive literature review.

Potzger, J. E. 1953. **History of forests in the Quetico-Superior country from fossil pollen studies.** Jour. Forestry 51: 560-565.

Analysis in 15 bogs shows an initial forest cover of spruce-fir or spruce-fir-pine. A long period of pine domination followed, during which no doubt a succession from jack pine to white-red pine occurred. Five major or minor successions and perhaps the same number of changes in climate stand out prominently. Indications are that pine is no longer a climatic climax but represents an edaphic or microclimatic climax determined by sandy soil.

Potzger, John E., and Ray C. Friesner. 1948. **Forests of the past along the coast of southern Maine.** Butler Univ. Bot. Studies 8: 178-190, illus.

Pollen analyses of six bogs between Mt. Desert Island and West Rockport indicate the following forest succession: spruce-jack pine to white pine (red pine), to white pine-birch-oak to white pine-hemlock-birch (with hemlock and birch alternating in representation), to a mixed coniferous-broadleaved forest complex of spruce, pine, hemlock, birch, oak, and beech. The results are discussed in relation to climatic changes.

Raup, Hugh M., and Reynold E. Carlson. 1941. **The history of land use in the Harvard Forest.** Harvard Forest Bul. 20, 64 pp., illus.

Early descriptions of timber and early records of land tenure and use show that the pre-colonial forests in Petersham were similar in composition and general topographic arrangement to the old forest types still remaining on certain tracts in the Harvard Forest. The complex mosaic of present forest types can be much simplified if they are related, through a time dimension, to the original arrangement of forest types as expressed by these relict woodlands.

Recknagel, A. B. 1942. **The cathedral pines.** Jour. Forestry 40: 344-345.

This virgin remnant in northwestern Connecticut consists of white pine and hemlock. Measured on a ¼-acre plot were 23 white pines 17 to 34 inches d.b.h., 4 to 5 logs high; and 26 hemlocks 6 to 24 inches d.b.h., 3 logs high. There was very little ground cover or reproduction of any sort.

Society of American Foresters. 1954. **Forest cover types of North America (exclusive of Mexico).** 68 pp. Soc. Amer. Foresters.

In the Northern Forest Region, three forest-cover types are recognized in which white pine is a major component: white pine-northern red oak-white ash, white pine, and white pine-hemlock. All are typically found on fresh to moist sites. White pine is listed as associate species in many other cover types. In the Central Forest Region, a white pine-chestnut oak type on dry sites is listed. For each cover type the definition and composition, nature and occurrence, and transition forms and variants are given.

Society of American Foresters, New England Section. 1922. **Forest region and type classification for New England.** Jour. Forestry 20: 122-129, 795-798.

Three forest regions are recognized in New England. The central New England or white pine region, a transition belt between the hardwoods of northern and southern New England, is characterized by white pine and a wide variety of hardwoods. The forest types occurring in these regions are described by composition, origin, location, and importance.

Stallard, Harvey. 1929. **Secondary succession in the climax forest formations of northern Minnesota.** Ecology 10: 476-547.

In a detailed study of the forests of northern Minnesota, a pine-hemlock climax represented chiefly by red and white pine, and a beech-maple climax were recognized. A number of secondary successions leading to these climaxes are described and their site associations are discussed. White pine consociations succeed aspen-birch, aspen-tamarack, oak, and probably tamarack-spruce. The role of fire is discussed and reasons for the dominance of pine are suggested.

Stearns, Forest. 1950. **The composition of a remnant of white pine forest in the Lake States.** Ecology 31: 290-291.

The dominant stand consisted of a few old white pines up to 40 inches in diameter and thought to be 390 years old. The second story was white pine, hemlock, and paper birch, 160-175 years old. The understory, 1 to 8 inches in diameter, was mostly hemlock, the rest sugar maple. Small reproduction was sparse — mostly sugar maple with occasional white pine and hemlock.

Transeau, Edgar N. 1905. **Forest centers of eastern America.** Amer. Nat. 39: 875-889, illus.

Four great forest formations are recognized by the author. Each formation is made up of many societies bearing a definite successional relationship to one another. It was found that if the ratios of rainfall to evaporation were plotted on a map, they would show climatic centers that correspond well with centers of plant distribution. The northeastern conifer region, centering in the St. Lawrence Basin, has white pine as one of its major components.

Veatch, J. O. 1928. **Reconstruction of forest cover based on soil maps.** Mich. Agr. Expt. Sta. Quart. Bul. 10: 116-126, illus.

From notes on forest distribution collected during several years of soils mapping in Michigan, the author offers examples of maps showing the original forest distribution and the observed relations between soils and vegetation. White pine is shown to be a major component of the original forest types on two soil-type groups, of which the Grayling and Roselawn soil series are prominent members.

White Pine Forest Association. 1912. **The white pine forest of Ogle County, Ill.** 18 pp., illus. White Pine Forest Assoc., Oregon, Ill.

Description of the 500-acre tract that contains the only natural white pine forest in Illinois. Although there is strong competition from a wide variety of hardwoods, the pine is reproducing itself here.

Whitford, Harry Nichols. 1901. **The genetic development of the forests of northern Michigan.** Bot. Gaz. 31: 289-325, illus.

Traces the life history of the vegetation on four different physiographic formations. The climax plant growth in each case is a hardwood-hemlock association. White pine is considered to occupy the transition zone between the hardwood-hemlock and other coniferous associations; it is the most mesophytic of all the pines. Emphasizes the physiographic restrictions on the rate of succession toward the climax.

Wilde, S. A. 1933. **The relation of soils and forest vegetation of the Lake States region.** Ecology 14: 94-105, illus.

Segregates forest soils into three main ecological groups: those where three roots are (1) permanently, (2) periodically, or (3) never under the direct influence of the water table. The importance of soil texture is stressed in the latter group. These soils are grouped further as sandy, loamy, and clay soils. In general, pines are associated with the sandy, hardwoods with the loamy, and mixed hardwoods and conifers with the clay soils. The further effects of profile development and of clay soil structure on forest associations are described.

Young, Vernon A. 1933. **Hardwood invasion in a comparatively old white pine afforested area.** Ecology 14: 61-69, illus.

Data from an old white pine stand on well-drained, medium loam soil, with calcium influence, in Syracuse, N. Y., strongly indicate the severe reaction of hardwood invasion in small areas. Under silvicultural treatment, white pine made fair growth for at least 50 years, but the stand was unable to control the environment. The hardwoods, undoubtedly the most destructive biotic enemy of afforested conifer areas in New York, made a successful invasion and threatened complete dominance.

FINANCIAL ASPECTS : CASE HISTORIES

Bryant, R. C. 1917. **Silviculture at Axton and in the Adirondacks generally.** Jour. Forestry 15: 891-895.

Between 1898 and 1903 Fernow cleared and burned old-growth hardwoods and planted Scotch, red and white pine, and Norway spruce. Although they have been unmanaged since planting, the plantations have grown well and are successful. Recommends that white pine and Norway spruce be planted on the better soils and that Scotch pine and red pine be planted on the poorer ones.

Cline, A. C. 1931. **The William H. Walker Forest and wood-using industry.** Jour. Forestry 29: 611-612.

A brief account of how the forest and the wood-working plant (all since inundated by the Swift River reservoir) were built up together as a profitable sustained-yield unit.

Cline, A. C., and C. R. Lockard. 1925. **Mixed white pine and hardwood.** Harvard Forest Bul. 8, 67 pp.

Traces the history of the white pine woodlot and presents a study of competition in natural pine-hardwood stands. It is evident that white pine will not maintain itself in pure stands on most sites in central New England and that past cutting has resulted in a continual degradation of the stands with poorer and poorer hardwoods. It is suggested that the best composition in this region is 50 percent white pine in groups and 50 percent better hardwoods, including red oak, white ash, basswood, and birch. The advantages of the mixed pine-hardwood stand over pure pine are set forth and compared economically.

Cromie, George A. 1938. **Shaker Pines Forest.** Jour. Forestry 36: 77-78.

The property consists of 290 acres of which 60 acres are covered with a red and white pine stand that originated from a broadcast sowing of mixed pine and buckwheat seed beginning in 1871. A corporation formed by leading conservationists had purchased the property to hold and manage. It was planned to establish a demonstration of good practical forestry and to prove, if possible, that such a tract can be managed on a sustained-yield basis.

Dana, Samuel T. 1930. **White pine region.** ***In*** **Timber growing and Logging practices in the Northeast.** U.S. Dept. Agr. Bul. 166: 55-79, illus.

Previously published material is organized into a helpful guide to the management of the principal forest types—white pine, transition hardwoods, and gray birch. Regeneration, methods of cutting, clearings and thinnings, slash disposal, protection, and yields are discussed. Material on fire protection, planting, logging, forest areas, and utilization for the Northeast as a whole is given elsewhere in the bulletin.

Eyre, F. H., and P. J. Zehngraff. 1948. **Red pine management in Minnesota.** U.S. Dept. Agr. Dept. Cir. 778, 70 pp., illus.

Throughout this bulletin there is information on white pine old growth, reproduction, ecology, and management in the white and red pine forests of Minnesota.

Federal Reserve Bank of Boston. 1953. **Here's convincing evidence that good forest management pays.** New England Farm Finance News 8 (1): 1.

A brief history of a 50-acre white pine lot in Barnet, Vt., that has been under continuous management since 1914. Originally it contained about 600,000 board feet; now it contains 800,000 board feet. During the period, 575,000 board feet have been harvested, 175,000 in an initial thinning and most of the rest since 1940.

Ferree, Miles J. 1952. **Report presented at the 1952 summer meeting of the New York Section, Society of American Foresters.** N.Y. State Univ. Coll. Forestry, 6 pp.

Summary table of the growth, development, and financial aspects of plantations of Norway spruce, white pine, red pine, Scots pine, and larch in Dutchess and Lewis Counties, N. Y. Definitions of plantation site qualities for the area of study are included. Reports wide spacing of plantations is most profitable.

Fisher, R. T. 1916. **Utilization and round-edge lumber.** Soc. Amer. Foresters Proc. 11: 386-393.

Describes the many uses of round-edge lumber and the close utilization of it in specialty markets.

Fisher, Richard Thornton. 1921. **The management of the Harvard Forest, 1909-1919.** Harvard Forest Bul. 1, 27 pp., illus.

A brief description of the area and its potentials for management together with a statement of objectives, silvicultural policy, and accomplishments. The allowable cut was about ¼ million board feet annually. Details cutting methods used.

Fisher, Richard T. 1924. **Close utilization in New England.** ***In*** **Report of the National Conference on Utilization of Forest Products.** U.S. Dept. Agr. Misc. Circ. 39: 24-27, illus.

On the Harvard Forest and in the surrounding area, close utilization has provided additional income to finance the shelterwood cuttings and later weedings necessary to ensure a new crop.

Foster, J. H. 1915. **Present forest tax situation in New Hampshire.** Forestry Quart. 13: 474-480.

Some 126 woodlots in New Hampshire were studied with respect to assessed valuation for tax purposes. Most of the woodlots were second-growth white pine of average value, and the majority of them would not have come onto the market normally for 10 to 20 years. Discusses effect of increases in tax assessments on premature cutting of white pine stands.

Foster, Clifford H., and Burt P. Kirkland. 1949. **The Charles Lathrop Pack Demonstration Forest, Warrensburg, N.Y. Results of twenty years of intensive forest management.** Charles Lathrop Pack Forestry Foundation, 36 pp. Washington.

A brief review of the early history, development, objectives and management of the Forest. Outlines silviculture for white pine, hemlock, and hardwoods, as applied on the Forest. The importance of careful utilization and market development to better forest management is stressed. Includes a financial analysis of results of management on the Forest.

Foster, Clifford H. 1953. **The importance of timber quality as a goal in silviculture.** Jour. Forestry 51: 487-490.

The success of silviculture is judged by the quality and quantity of usable wood produced. Intensive silvicultural practices should be applied to a few choice species on the best and most accessible sites. Too often foresters have avoided work of important future significance on the grounds that it would not give immediate net return. Cites methods to produce high-quality white pine.

Frothingham, E. H. 1914. **White pine under forest management.** U.S. Dept. Agr. Bul. 13, 70 pp., illus.

This bulletin, a complete treatment of the subject, is still "the bible" of white pine in New England. It covers white pine's general suitability for management, geographical range, and place in the history of lumbering. General characteristics of old-growth and second-growth stands are discussed and the section on silvical characteristics includes description of site requirements, form, natural reproduction, growth of individual trees and stands. Other sections are devoted to planting, protection, tables of yield, and management finances.

Gedney, D. R., and T. W. McConkey. 1951. **1-man chain saw may save manpower in logging white pine.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Res. Note 2. 3 pp.

A study of logging-cost records for over ½ million board-feet of white pine timber indicates that felling, limbing, and bucking operations with 1-man power saws uses about 1½ man-hours per thousand board feet less labor than when the work is done with 2-man power saws. The logs produced varied in size from 11 to 26 logs per thousand board feet.

Gevorkiantz, S. R., and Raphael Zon. 1930. **Second-growth white pine in Wisconsin: its growth, yield, and commercial possibilities.** Wis. Agr. Expt. Sta. Res. Bul. 98, 40 pp.

White pine on average sites will produce 10,500 board feet at 40 years, 36,500 board feet at 60 years, and 59,000 board feet at 80 years. On poor sites the yield at 40 years will be only 2,400 board-feet but on the best sites the yield will be 19,000 board-feet at the same age. Detailed tables of volume and yield. Yields of white pine in Wisconsin are shown to be about the same as those in New England.

Graves, Henry Solon, and Richard Thornton Fisher. 1903. **The woodlot: a handbook for owners of woodlands in southern New England.** U.S. Dept. Agr. Bur. Forestry Bul. 42, 89 pp., illus.

Management of hardwoods and white pine in Massachusetts and Connecticut is discussed briefly. Various cultural measures are illustrated and discussed in some detail.

Haasis, Ferdinand W. 1930. **Forest plantations at Biltmore, North Carolina.** U.S. Dept. Agr. Misc. Pub. 61. 30 pp., illus.

A guide to plantings, sowings, and experimental thinnings of about 40 species; the majority of the successful stands were white or shortleaf pine. Most of the plantations were very dense (2,000+ trees per acre) but were never thinned. The experimental thinnings on small plots greatly increased net growth. Recommends certain choices of species and planting methods. Concludes that it is unwise to select species to plant simply because of their prevalence in the virgin forest. Changes in soil and environment from past use must also be considered.

Hawes, A. F. 1911. **The management of Vermont forests with special reference to white pine.** Vt. Agr. Expt. Sta. Bul. 156: 99-139, illus.

Designed for owners of small woodlands in Vermont, this manual gives yield and growth tables for white pine, and discusses management of pure and mixed pine stands with special attention to thinnings and improvement cuttings, final cuttings, regeneration, growth and yield, protection, marketing, and costs and returns. Some case histories.

Hawkins, Guy C. 1924. **How one wood-using industry has made use of a forester.** Jour. Forestry 22: 140-148.

An account of the forest operations of the New England Box Company in central New England, which uses 40 million board feet of white pine annually. To meet these needs, the company has set up working groups around each of its mills. Forestry practices include planting, weeding, and thinning.

Hawley, Ralph C., and Robert T. Clapp. 1942. **Growing of white pine on the Yale Forest near Keene, New Hampshire.** Yale Univ. School Forestry Bul. 48. 44 pp., illus.

A discussion of the management of the forest where pure white pine stands for lumber production is the objective. Describes physical facts of the forest and discusses suitable practices for harvesting merchantable wood and timber, establishing the new crop, improving the new crop by pruning and thinning, and protecting the crop.

Hawley, Ralph C., and Harold J. Lutz. 1943. **Establishment, development, and management of conifer plantations in the Eli Whitney Forest, New Haven, Connecticut.** Yale Univ. School Forestry Bul. 53. 81 pp., illus.

White pine and Norway spruce planting should continue on the old fields of southern Connecticut. Recommends a 60-to-80-year growing period, followed either by a forest of hardwoods, naturally seeded, or by pine or spruce in varying mixture with hardwoods. Original plantings may be in pure stands or in small grouped mixtures of pine and spruce, and possibly red oak.

Heiberg, Svend O. 1942. **Cutting based upon economic increment.** Jour. Forestry 40: 645-651.

Charts the economic increment of white pine and hemlock for trees of three quality classes and diameters from 8 to 20 inches (white pine), the current realization value, the number of rings per inch needed to earn different rates of interest. Charts are based on a detailed logging and mill study at the Pack Forest, Warrensburg, N. Y. The application of cutting for economic increment and its effect upon the form of the forest are discussed.

Heiberg, Svend O. 1945. **Does economic cutting pay?** Jour. Forestry 43: 109-112.

An example from the Pack Forest, Warrensburg, N. Y., of cutting based on economic increment. Cutting has increased earnings and put the stand in condition for continued high earnings under proper treatment. Discusses the details of application, particularly the relation of the biological requirements of the forest to economic increment.

Hersey, Edmund. 1896. **Facts gathered by observation and experience relating to the white pine (*Pinus strobus* L.).** Bussey Inst. Bul.: 373-385.

Discusses the natural reproduction of white pine and means of supplementing it by seeding or by transplanting wildlings. The importance of soils to reproduction and to choice of a rotation is stressed. In Plymouth County, Mass., mill scale yields of 50,000 feet of 5/8-inch box boards per acre, in 30 to 35 years, are not uncommon. On the better soils even greater volume growth is possible, and individual trees grow to about 20 inches stump diameter in the same period. Discusses the merits of short rotations for rough lumber versus long rotations for clear material.

Kittredge, Joseph, Jr. 1929. **Forest planting in the Lake States.** U.S. Dept. Agr. Bul. 1497, 88 pp., illus.

A comprehensive treatment of the subject. White pine can be planted on some of the sandy loam soils, but best sites for white pine are found on the loams or any soil that has been cleared and cultivated. On the sandier soils, white pine should be planted only if there is more than 40 percent cover to protect the trees. On the finer soils, cover is not so important. Planting may be done in either spring or fall with 2-1 or 3-0 stock.

Lyford, C. A., and L. Margolin. 1906. **Forest conditions in southern New Hampshire.** *In* N.H. Forestry Comn. Rpt. 1905-06: 161-276, illus.

A treatise on the condition and management of the forests of southern New Hampshire. The authors deal primarily with white pine, for which they discuss the distribution and silvics, make silvicultural recommendatons for intermediate treatments and regeneration, and provide yield tables and other mensurational tools as aids for management. These yield tables are the first developed in the Northeast.

Moore, J. C. 1945. **Christmas tree production.** Ala. Agr. Expt. Sta. Circ. 92, 15 pp.

White pine is one of several species that gave promise of making good Christmas trees when grown in Alabama and the Southeast. They also provided erosion-control cover on sloping lands where cultivated crops are inadvisable.

New Hampshire Forestry Commission. 1922. **Management of farm woodlots.** N.H. Forest Comn. Bien. Rpt. 1921-22: 128-151.

Briefly describes the economic position and the condition of the woodlot in southern New Hampshire. A discussion of woodlot care and improvement emphasizes the growth of white pine. Margolin's yield table for white pine is reprinted and the financial rotation is discussed. Natural stands yield the greatest net profits with a rotation of 35 to 40 years while plantations reach financial maturity at about the same age.

New Hampshire Forestry and Recreation Commission. 1937. **Woodlot management.** N.H. Forest Comn. Bien. Rpt. 1935-36: 163-167.

A brief review of general considerations. To grow white pine, blister rust and grazing must be eliminated and special measures taken against the white-pine weevil and in some cases the gypsy moth.

Pettis, C. R. 1909. **How to grow and plant conifers in the Northeastern States.** U.S. Dept. Agr. Forest Serv. Bul. 76, 36 pp., illus.

Briefly explains the more important phases of seed procurement, nursery establishment, nursery practice, and field planting. Much of the experience related has been gained with white pine. Cost calculations on the various operations are included.

Rendall, R. E. 1923. **Bates Forest.** Jour. Forestry 21: 162-172.

The acquisition and first steps in management of the Bates Forest in Maine (now included in the Massabesic Experimental Forest) are described. The forest is largely in white pine types, but these are considered temporary; hemlock, pitch pine, and white-cedar swamp are recognized as the permanent types.

Rudolf, Paul O. 1950. **Forest plantations in the Lake States.** U.S. Dept. Agr. Tech. Bul. 1010, 171 pp., illus.

A comprehensive bulletin on forest planting and plantation maintenance for the Lake States region. Sections deal with the history and background of planting; direct seeding; where, what, why, how, and when to plant; cost of planting; protection, growth, and culture of plantations; judging the success of plantations; record keeping; and the necessary groundwork in reforestation planning.

Simmons, J. R. 1915. **The older forest plantations in Massachusetts.** 38 pp., illus. Boston.

From 1820 to 1880, 10,000 acres of white pine were planted. Some of the plantations showed a current annual growth of 1,000 board feet per acre and the mean annual growth was frequently about 500 board feet per acre.

Spring, S. N. 1905. **The natural replacement of white pine on old fields in New England.** U.S. Dept. Agr. Bur. Forestry Bul. 63, 32 pp., illus.

Concludes that the extension of white pine on old fields and pastures has been vigorous in the past and that it remains so where seed trees are present. Reestablishment of white pine can be assured by leaving seed trees. Suggestions are also given for tending young stands.

Spurr, Stephen H., and A. C. Cline. 1942. **Ecological forestry in central New England.** Jour. Forestry 40: 418-420.
In central New England it is evident that plantations and the old-field white pine, aspen, gray birch-red maple, and paper birch types are expensive and biologically unsound for forest management except where they form a physiographic climax. Silvicultural practice should aim at low-cost production of late successional forest types—the hardwood-hemlock associations.

Toumey, J. W. 1914. **Forest planting in New England as an investment.** Forestry Quart. 12: 538-543.
The profitability of planting in New England is discussed, using several profitable white pine plantations as examples. Planting will return a good income if white or red pine is planted on first—or sometimes second-quality sites near good markets for thinnings and other expected products, if the land is equitably taxed, and has good fire protection. Only a limited area meets these requirements.

Toumey, James W. 1932. **The Yale demonstration and research forest near Keene, New Hampshire.** Yale Univ. School Forestry Bul. 33. 106 pp., illus.
This report on the operation of the forest since 1913 reviews the research and accomplishments as well as the organization of the property as a business enterprise. The organization, records, management aims for each major type, inventory, growth, and yield of the forest are all described. Most of the area is devoted to growing white pine pure or in mixture.

Toumey, J. W., and R. C. Hawley. 1916. **The Keene Forest.** A preliminary report. Yale Univ. School Forestry Bul. 4. 25 pp.
A statement of the early organization and plan of management of the forest. Out of 900 acres in the property, 400 acres are in white pine.

Wackerman, A. E. 1924. **Growth of the "grayling pine".** Jour. Forestry 22:796-797.
Report on growth of a 76-acre tract of virgin white pine (1884-1924) in lower Michigan.

Zon, Raphael. 1928. **Timber growing and logging practice in the Lake States. Measures necessary to keep forest land productive and to produce full timber crops.** U.S. Dept. Agr. Bul. 1496, 64 pp., illus.
Describes the four principal forest-type groups of the Lake States. Common logging practices, fire, and other factors affecting the productive capacity of the forest are discussed. In the Norway and white pine types, partial cutting is recommended. This means leaving at least 10% and perferably 20% of the merchantable volume and all the smaller trees until the area has become fully stocked with reproduction.

TREE SEED

Baldwin, H. I. 1934. **Effect of after-ripening treatment on germination of white pine seeds of different ages.** Bot. Gaz. 96: 372-376, illus.
Germination tests were made of several lots of seed of different ages. In most cases after-ripening for several weeks at 8 to 10° C. increased the rate of germination markedly. This increase was most prominent in the case of seed 2 to 3 years old. Germination descreased with age, that of stratified seed more rapidly than that of untreated control seed.

Baldwin, Henry I. 1935. **Catalase activity as a measure of viability of tree seeds.** Amer. Jour. Bot. 22: 635-644, illus.

Fourteen lots of white pine seed were among those tested. It was found that the catalase quotient (average oxygen evolution of stimulated seed over that of dry seed) was high in seed lots of high viability and low in seed lots of low viability. The seed lots varied from 0 to 84.5% in germinative energy.

Baldwin, H. I., and Florence Flemion. 1941. **Rapid method for testing white pine germination.** N.H. Forestry and Recreation Comn. Fox Forest Notes 30, 1 p.

The excised embryo germination test of white pine seed was compared with germination after planting directly in the soil and with stratification before planting. There was a close correlation between the exised embryo test and the actual percentage germination of the stratified seeds so that a good approximation of germinative energy can be obtained in 10 days instead of the usual 12 weeks.

Barton, Lela V. 1930. **Hastening the germination of some coniferous seeds.** Amer. Jour. Bot. 17: 88-115.

Results of stratification for varying periods at a number of different temperatures (constant) are compared with several other treatments. White pine was difficult to germinate but stratification (especially at 10° C. for 2 months) gave much better germination than other treatments.

Bibby, K. M. 1953. **Experiments in pregermination treatment of tree seed.** New Zeal. State Forest Serv. Forest Res. Notes 1 (7): 9-16.

Pre-chilling in moist conditions before germination greatly improved rate and amount of germination in white pine.

Blumer, Jacob C. 1908. **Amerikanische Versuche mit Kiefernsamen.** Ztschr. f. Forst- u. Jagdw. 40: 236-240.

Describes germination tests with seeds of American pine in the U. S. Department of Agriculture Seed Laboratory. At a temperature of 52° F. there was no germination of white pine at 100 days, but with temperatures varying beween 68 and 95° F. germination was 85% in 10 days. White pine seed, the most resistant to injury by high temperatures, withstood a temperature of 122° F.

Brooks, R. O. 1951. **Chemical weeding as applied to forest nursery practice.** Pa. Dept. Forests and Waters 3 (2): 42-43, 47-48.

Good results were obtained with applications of Sovasol and Stanisol to nursery beds of white pine. Light applications at a very early stage are recommended.

Eliason, E. J. 1939. **Storage of eastern white pine seed for seven years.** N.Y. State Conserv. Dept. Forest Invest. Note 29, 2 pp.

Tests confirm the value of air-tight storage of conifer seed at low constant temperature for maintaining viability. White pine seed stored in sealed carboys, in a seed vault having a temperature of 36-38° F. and 85-90% relative humidity, showed 87% germination at the end of 7 years.

Eliason, E. J. 1942. **Data from cone collections of various species in New York.** N.Y. State Conserv. Dept. Forest Invest. Note 39, 1 p.

Summarizes data from special collections made since 1927 for various experiments. Five lots of white pine were collected. Per bushel of green cones they averaged 27 pounds, 521 cones, and 15.3 ounces of seed.

Gravatt, A. R., D. H. Latham, L. W. R. Jackson, and others. 1940. **Multiple seedlings of pines and Douglas fir.** Jour. Forestry 38: 818, illus.

Two cases in which two well-developed white pine seedlings developed from a single seed are among those reported. One case was in a lot of 6,450 seedlings.

Heit, C. E. 1938. **Stratification technique for white pine.** N.Y. State Conserv. Dept. Forest Invest. Note 12, 1 p.

Stratification period for white pine should be 20 days, based on results from test periods of 10 to 50 days. Place the seed on a pod and wick in a small germinator and cover with a glass funnel. Temperature should be maintained at 36 to 40° F. This procedure will give 10 to 15% better germination than stratification in sand.

Johnson, L. P. V. 1946. **Effect of chemical treatments on the germination of forest tree seeds.** Forestry Chron. 22: 17-24.

Chemical treatments were tested, in comparison with stratification and pre-soaking, for their effects on germination of the seed of many tree species. With white pine, significant increases in percentage germination were obtained from stratification for 50 days.

Johnstone, G. R. 1940. **Further studies on polyembryony and germination of polyembryonic pine seeds.** Amer. Jour. Bot. 27: 808-811, illus.

Eleven species of pine bear multiple seedlings. The seeds of five species were dissected to reveal true polyembryony. Reports unpublished observation by Meier that approximately 2% of white pine seed is polyembryonic.

Kirkham, Dayton P. 1930. **Germination of seed from different parts of cone and crown.** Minn. Univ., The Gopher Peavy: 30-36.

Concludes from limited germination tests that viability of white pine seed is related more closely to the position of the cone on the tree than to the position of the seed in the cone. Seeds from the lower crown and from the basal portion of the cone germinated best.

Knecht, Hans. 1931. **Über die Beziehungen zwischen Katalaseaktivität und Vitalität im ruhenden Samen.** Bot. Centbl. Beih. Abt. 1, 48: 229-313, illus.

With individual seeds the author found no relation between catalase activity and vitality. In two pine species studied, medium and high catalase activity was associated with high germination and low activity with low germination; but with white pine high catalase activity was associated with low germination and medium and low activity with high germination.

Koblet, Rudolf. 1932. **Über die Keimung von Pinus strobus unter besonderer Berücksichtigung der Herkunft des Samens.** Schweiz. Bot. Gesell. Ber. 41: 199-283.

The effects of storage and seedbed temperatures on germination of white pine seed of different geographic origins was studied. There was no apparent relation between origin and germination temperature. Germination was rapid and complete at a constant temperature of 6 to 12° C.; at higher constant temperature or with daily alternation between low and high temperatures, germination was lower. Chemical analyses showed that poor germination was not due to lack of sugar. In the seedbed, seed showed an increase in pH, especially at higher temperatures.

Lake States Forest Experiment Station. 1930. **Pre-treatment of white pine seed for spring sowing.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 29, 1 p.

White pine seed for spring planting should be stratified in fine sand or sawdust moistened with 1 to 2 times its weight of water for about a month. The temperature should be maintained at 33 to 50° F. After sifting from the sand or sawdust, the seed should be sowed immediately.

Lake States Forest Experiment Station. 1932. **Dryness—key to storage of pine seed.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 56, 1 p.

Red pine seed dried to less than 5% moisture content and white pine seed dried to about 6% keep well for 3 to 4 years, particularly if stored at temperatures below 40° F. Seed should be stored in sealed containers so it will not absorb moisture.

Lake States Forest Experiment Station. 1940. **When to pick pine cones.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 170, 1 p.

Criteria of ripeness are given for red, white, and jack pine cones, and the method of testing is described. White pine cones are ripe when they are yellowish green in color with brown on scale tips and when the specific gravity is 0.92.

Lake States Forest Experiment Station. 1941. **Testing cone ripeness.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 176, 1 p.

Describes a field kit for flotation tests. White pine cones are ripe when they float in linseed oil—usually from August 27 to September 6 in lower Michigan.

Rietz, R. C. 1939. **Kiln design and development of schedules for extracting seed from cones.** U.S. Dept. Agr. Tech. Bul. 773, 70 pp., illus.

Results of studies of cone opening, seed yield, cone moisture reduction, seed moisture reduction, viability of seed from kiln-dried cones, and seed heating are reported for white, red, and jack pine. For extraction of white pine seed it is recommended that the cones be pre-cured.

Roe, Eugene I. 1948. **Viability of white pine seed after 10 years of storage.** Jour. Forestry 46: 900-902.

On the basis of a study with five temperature and five moisture levels, the author recommends that white pine seed be dried to not more than 7% moisture content and should then be stored in moisture-proof containers at a temperature of 36° F. Under these conditions viability should be fully retained for at least 10 years.

Rohmeder, E. 1939. **Curing arrested germination in seeds of Weymouth pine, Douglas fir, and larch by pre-treatment under cold and wet conditions.** Forstwiss. Centbl. 61: 393-406.

Experiments at the Forstliche Samenprufstelle in Munich confirmed the value of pre-treatment of Weymouth pine seed on the lines developed by Schwappach, Grisch, Lakon, and Koblet. Except for very poorly germinating samples, the rate and percentage of germination was greatly increased by moist storage at 2 to 4° C. for 28 days.

Rudolf, Paul O. 1940. **When are pine cones ripe?** Minn. Acad. Sci. Proc. 8: 31-38.

Ripeness of white pine cones was closely associated with color and specific gravity of the cones. Cones with a specific gravity of 0.973, cone scales tipped with brown, cones yellowing and a few brown, germinated better than 80% of the seed and may be considered ripe. These conditions coincided with the time squirrels began to cut cones.

Schmidt, W. 1925. **Über Vorquellung und Reizbehandlung von Koniferensaatgut.** Zellstimulationsforschungen 1: 355-368.

White pine seed stored dry will not germinate without soaking in water. Storage in a cool, moist room for 30 days after a swelling period of 16 hours has given 78% germination from dry-stored seed. Soaking in a 1% solution of hydrogen peroxide instead of water has given 81% germination in 60 days.

Schubert, G. H. 1954. **Viability of various coniferous seeds after cold storage.** Jour. Forestry 52: 446-447.

Germination capacity was tested for seed lots of many species stored under generally favorable condition at 41° F. in 5-gallon cans with tight lids for 2 to 24 years. A single lot of eastern white pine seed stored more than 10 years gave no germination.

Sibenik, M. 1952. **Mocenje semena zelenega bora pred setvijo-odlicen uspeh. (Excellent results obtained by soaking seeds of Pinus strobus before sowing.)** Gozd. Vestn. 10 (7): 217.

Seeds were soaked for 14 days in water that was changed every other day; when sown after some drying, they germinated 100%. Controls had very poor germination.

Spurr, Stephen H. 1944. **Effect of seed weight and seed origin on the early development of eastern white pine.** Jour. Arnold Arbor. 25: 467-480, illus.

In a controlled experiment it was determined that seed weight is directly related to germination, survival, and the early size of the plant. The correlation between seed weight and shoot weight diminishes as the plant ages, but is still noticeable after 3 years. Seed origin is related to germination, appearance, moisture content, and seedling growth. The influence of seed origin on plant size is as strong at the end of the third year as at the end of the first growing season.

Tillotson, C. R. 1921. **Storage of coniferous tree seed.** Jour. Agr. Res. 22: 479-510.

Seed of white pine and 5 other conifers was stored at 13 geographic locations under 3 temperature conditions and in 5 types of containers. Air-tight bottles maintained seed quality far better than any other containers. Seed so stored was not affected by temperature or location. After 5 years in sealed bottles, white pine seed germinated 44 to 51%. After 10 years in sealed bottles that were opened once at the end of the 5th year, white pine seed failed to germinate.

Toumey, J. W., and W. D. Durland. 1923. **The effect of soaking certain tree seeds in water at greenhouse temperatures on viability and the time required for germination.** Jour. Forestry 21: 369-375.

Seed of different species differ widely in response to pre-soaking. White pine is in a group of species whose seed normally germinates in late spring. In tests, white pine seed was soaked from 0 to 30 days; the most rapid and most complete germination occurred with seed that had been soaked 10 days.

Toumey, J. W., and C. L. Stevens. 1928. **The testing of coniferous tree seeds at the School of Forestry, Yale University, 1906-1926.** Yale Univ. School Forestry Bul. 21, 46 pp.
Results of extensive tests on the seed of 36 species. In 26 lots of white pine seed tested, the number of seeds per pound varied from 24,000 to 43,000, an average of 28,000. Highest germination capacity was 94%, lowest 15%, average 67%. There was great variation in the time required for germination.

United States Forest Service. 1948. **Woody-plant seed manual.** U.S. Dept. Agr. Misc. Pub. 654, 416 pp., illus.
A comprehensive manual with chapters on seed and its development, seed production and dispersal, seed source, collection, processing and storage of seed, pretreatment, and seed testing. Part 2 gives, for white pine and many other species, all the available information on the above subjects.

Wright, Jonathan W. 1945. **Influence of size and portion of cone on seed weight in eastern white pine.** Jour. Forestry 43: 817-819.
In a cone collection from six trees, the fresh weight of the seed was found to increase significantly from small to large cones and from the apical to the basal portion of the cone. There were also significant differences in seed weight among trees. No obvious correlation was found between seed or cone size and the age, diameter, or growth rate of the parent.

NURSERY PRACTICE : VEGETATIVE PROPAGATION

Burns, George P. 1914. **Development of white pine seedlings in nursery beds.** Vt. Agr. Expt. Sta. Bul. 178: 127-144, illus.
Nursery and greenhouse tests produced results from which the following conclusions were drawn. Damping-off of seedlings can be controlled with formaldehyde or sulfuric acid. In sandy soils, seed should be planted not less than ½ inch deep. If seed is sown early in wet weather, no top shade is needed to get an even stand. If seed is sown late in dry weather, the surface soil must be kept moist by watering or by full shade top.

Burns, George P. 1927. **Leaf efficiency in thrifty and stunted white pine seedlings.** Vt. Agr. Expt. Sta. Bul. 267, 27 pp., illus.
From a study of supplemental watering of white pine seedlings in nursery beds, it was concluded that stunting is due primarily to intense root competition, which may be caused by lack of rainfall or the use of too much seed. From the limited data it seemed that leaves of stunted trees are as efficient for wood production per unit of dry weight as those of the more thrifty trees. The stunted trees recovered quickly when transplanted to favorable conditions. Density of the crown is an indication of the amount of available water.

Chittenden, A. K., and P. W. Robbins. 1928. **Best white pine seedlings follow fall planting.** Mich. Agr. Expt. Sta. Quart. Bul. 10: 95-97, illus.
Seed sown the last of October in the Upper Peninsula of Michigan and from November 10 to 25 in the Lower Peninsula will give better 1-year-old seedlings than spring sowing. The roots are larger, stronger, and more branching, the loss from damping-off is reduced by early germination, and germination is faster and more regular, with little or no seed holding over to the second spring before germinating.

Deuber, C. G. 1940. **Vegetative propagation of conifers.** Conn. Acad. Arts and Sci. Trans. 34: 1-83.

Dormant cuttings of white pine rooted better than summer cuttings but there was no marked seasonal trend in winter. Cuttings from younger trees, especially from seedlings 2 to 4 years old, rooted better and more consistently than those from older trees. Removing the lower needles and waxing the cuttings both proved to be detrimental. Small cuttings 2 to 4 inches long, taken from lateral shoots, survived better and rooted more abundantly than larger ones, especially those from terminal shoots.

Deuber, Carl G. 1942. **The vegetative propagation of eastern white pine and other five-needled pines.** Arnold Arboretum Jour. 23: 199-215.

In rooting trials with white pine it was found that trees 2 to 6 years old possessed considerable natural ability to root, but usually rooting from trees 8 to 90 years old was very poor or a complete failure. Treating young stock with auxins in various ways was favorable to rooting, except when mixed with lanolin as a paste. Treatment with sugar and a variety of chemicals did not appreciably influence root formation.

Doran, W. L. 1946. **Vegetative propagation of white pine.** Mass. Agr. Expt. Sta. Bul. 435, 16 pp.

In tests of cutting season, type of cutting, and rooting medium, the best results were obtained by taking cuttings in late winter from the lower limbs of young trees. The cuttings should be small twigs from the last season's growth, with no needles removed. The treatment is completed by immersing the cuttings for a short time in a concentrated solution of indole-butyric acid and then setting them in sand-peat or sand-sedge for rooting, in a rooting room with a high relative humidity. White pine trees vary in their ability to root, but those that root successfully will do so in 3 to 5 months after treament.

Doran, William L. 1953. **The vegetative propagation of some forest trees.** Northeast. Forest Tree Improve. Conf. Proc. 1: 41-47.

The author has successfully rooted cuttings of a number of species, including eastern white pine. White pine does not root easily. In recent trials, cuttings from only 1 out of 16 quality white pine were successfully rooted. Rooting ability may well be as important a basis for selection as timber quality. Cuttings taken from the tips of lateral branches of young trees between December and March appear to root most successfully.

Eliason, E. J. 1938. **Toxicity of zinc sulphate to coniferous seedlings.** N.Y. State Conserv. Dept. Forest Invest. Notes 10. 1 p.

Zinc sulfate applied to nursery beds after sowing and sanding materially reduced number of weeds but did not affect germination or injure seedlings of white pine. Under certain dry conditions other conifers were injured.

Eliason, E. J. 1938. **Pre-germination in fall-sown seed beds.** N.Y. State Conserv. Dept. Forest Invest. Note 11. 1 p.

White pine germination and growth has been best in fall-sown beds, the very best in October. There was no fall germination in any of the beds sown at various dates in the fall. Results differed with other species.

Farrar, J. L., and N. H. Grace. 1942. **Vegetative propagation of conifers. XII. Effects of media, time of collection, and indolylacetic acid treatment on the rooting of white pine and white spruce cuttings.** Canad. Jour. Res. Sect. C 20: 204-211.

Semi-monthly cuttings from July to October were planted in different media: two types of sand and two peats (sedge and sphagnum) in different proportions. A series of concentrations of the acid in talc were dusted on the cuttings but showed no appreciable effort on rooting. Cuttings collected in late August and propagated in sedge peat rooted 62%. No other season of cutting or combination of media gave as good results.

Gruenhagen, R. H. 1940. **Growth substances of doubtful benefit for treatment of pine seeds.** Jour. Forestry 38: 739-740.

In the tests reported, applications of naphthalene-propionic acid and several concentrations of indol-3-acetic acid failed to control damping-off or to increase germination in white and red pine seeds.

Iowa Agricultural Experiment Station. 1946. **(Effect of 2,4-D on different tree species.)** Iowa Agr. Expt. Sta. Rpt. 253.

The effect of 2, 4-D on different tree species was tested at the State Forest Nursery with the object of using it on weeds if it proved harmless to trees. The new leaves of hardwoods were killed by this chemical. The succulent new growth of white pine and Douglas-fir was also affected.

Lake States Forest Experiment Station. 1939. **Thinning of conifer seedlings in the nursery produces bigger but fewer plantable trees.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 143, 1 p.

Red and white pine seedlings were root-pruned and thinned to several densities in the spring of the third year. The treatments increased the average weight and stem diameter of the seedlings but reduced the plantable number per square foot regardless of the acceptable planting size. The desired density should be obtained by reducing the amount of seed rather than by thinning.

Lake States Forest Experiment Station. 1942. **Root pruning—a labor saver.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 190. 1 p.

Root pruning of seedlings at the beginning of the third year produces planting stock nearly as good as 3-year transplants, especially if used for spring planting. The cost is considerably less. White pine 3-0 root-pruned stock had a survival in field planting of 73 to 98%.

Larsen, J. A., and W. G. Stump. 1939. **Some experiments with fertilizers for evergreen seedlings.** Iowa State Col. Jour. Sci. 13: 293-311, illus.

Describes nursery and greenhouse experiments on the effect of various organic and inorganic fertilizers on the growth of seedlings of white pine and several other conifers. In general, nitrogen fertilizers increased top growth and phosphorus fertilizers increased root growth. In the nursery a combination of fertilizers was most effective.

McIntyre, Arthur C., and J. W. White. 1930. **The growth of certain conifers as influenced by different fertilizer treatments.** Jour. Amer. Soc. Agron. 22: 558-567.
Fertilizer experiments were carried out with white pine in pots of sand and Hagerstown silt loam, and in Hagerstown silt loam nursery beds. In sand, all treatments were beneficial; but lime, alone or in combinations, produced the heaviest 2-year seedlings. In silt loam, dried blood at the rate of 200 pounds per acre gave the heaviest seedlings. Sodium nitrate and superphosphate, alone and in combinations, produced the next heaviest seedlings.

Mirov, N. T. 1938. **Vegetative propagation of white pine as a possible method of blister rust control.** Jour. Forestry 36: 807-808.
The author and J. H. Murray of Marsh Botanical Garden have been successful in rooting cuttings of white pine. The author took cuttings 3 to 4 inches long from young trees in December, put their tips in warm water for about 2 hours, and planted them in coarse sand. Temperature of the sand was maintained at 74 to 78° F. Roots appeared by the end of May.

Patton, R. F., and A. J. Riker. 1954. **Top growth and root development of rooted white pine cuttings.** Jour. Forestry 52: 675-677, illus.
Two- and 3-year-old rooted cuttings were compared with 2-2 seedlings in a checkerboard field planting. Survival after 7 to 9 years: cuttings 83%, seedlings 89%. Form and size of shoots were the same. Root systems of cuttings were adequate for growth and approached those of seedlings as plants grew older. Root pruning helped form good root systems on cuttings.

Petheram, H. D. 1927. **Season for sowing red and white pine seeds.** Jour. Forestry 25: 57-61.
Four seasons for sowing red and white pine seeds were tested: late fall, early spring, mid-spring, and summer. Results in the Cass Lake Nursery, in Minnesota, showed that a late-fall sowing had the best germination and the best 2-year survival, followed by an early-spring sowing. The summer sowing had good germination but poor survival and low-quality stock. A sample of each stock was field-planted and checked for survival over a 3-year period. In these tests the late-fall and early-spring sowings were generally the best and had the lowest cost per thousand in terms of survivors.

Reineke, L. H. 1942. **Effect of stocking and seed on nursery development of eastern white pine seedlings.** Jour. Forestry 40: 577-578.
A significant difference is found in seedling development when density is reduced: stems are longer, diameters increase, tap roots are longer, lateral roots increase, and more terminal buds develop. In short, reduced density of seedlings shortens the preparation time for planting stock.

Shirley, Hardy L., and Lloyd J. Meuli. 1939. **Influence of moisture supply on drought resistance of conifers.** Jour. Agr. Res. 59: 1-21.
Drought resistance of white, red, and jack pine seedlings was increased by subjecting them to moderate soil drought during the period of vegetative activity, but improved resistance did not depend solely upon the smaller shoots and greater root-shoot ratios developed. Exposure to severe dryness of soil temporarily weakened the plants and, unless followed by an ample period of recovery, rendered them more susceptible to drought. Improvement of drought resistance of Lake States pine seedlings by controlling the moisture supply in the nursery was demonstrated to be practical.

Snow, Albert G., Jr. 1940. **Rooting white pine cuttings.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Occas. Paper 11, 6 pp., illus.

Rooting was most successful with cuttings from younger trees and those farthest removed from the terminal leader. Maximum rooting was obtained by treating with indolebutyric acid followed by auxin dust. Cuttings from individual white pine trees showed considerable clonal variation in rooting ability.

Snow, Albert G., Jr. 1941. **Effect of needle removal on survival of white pine cuttings.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 38, 2 pp.

Any reduction of leaf area is detrimental to survival of white pine cuttings. Clipping the upper needles just above the bud usually resulted in mortality within 2 months. Mortality was attributed to loss of reserve materials such as starches, amino acids, and growth substances; possibly also to detrucive effect of fungi.

Snow, Albert G., Jr. 1941. **White pine propagation.** Jour. Forestry 39: 332-333.

The most successful rooting of white pine was obtained in media containing fungi. The fungi may help by providing an extra auxin supply or by aiding in the mineral nutrition.

Stoeckeler, J. H. 1949. **Control of weeds in conifer nurseries by mineral spirits.** U.S. Forest Serv. Lake States Forest Expt. Sta., Sta. Paper 17, 23 pp.

In white pine beds dosages of 50 to 75 gallons per acre controlled weeds less than 1 inch high and did not damage the pines, especially if the beds were shaded and true needles had formed.

Stoeckeler, Joseph H. 1950. **Can nurserymen produce white pine seedling stock comparable to transplants?** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 339, 1 p.

By growing 3-0 white pine seedlings at a nursery density of about 25 per square foot, stock comparable to 2-1 transplants can be produced at a lower cost. Densities from 13 to 81 seedlings per square foot were tested.

Thimann, Kenneth V., and Jane Behnke. 1947. **The use of auxins in the rooting of woody cutting.** Maria Moors Cabot Found. Pub. 1, 272 pp.

A tabulation of data and notes on the trials made. Many trials, some of them successful, were made with white pine.

Thimann, K. V., and Albert L. Delisle. 1939. **The vegetative propagation of difficult plants.** Arnold Arboretum Jour. 20: 116-136, illus.

This progress report on controlled trials with serveral species shows that cuttings from 3- or 4-year-old white pines rooted very well when treated with a strong (200 to 400 ppm) solution of indole-acetic acid. Application of a sugar solution following the auxin treatment increased rooting and decreased mortality.

Thimann, K. V., and Albert L. Delisle. 1942. **Notes on the rooting of some conifers from cuttings.** Arnold Arboretum Jour. 23: 103-109.

In white pine the individual needle bundles or brachyblasts form roots at least as readily as do ordinary cuttings, particularly if they are treated with auxins.

Thomas, J. E., and A. J. Riker. 1950. **Progress on rooting cuttings of white pine.** Jour. Forestry 48: 474-480.

From 50 to 90% of cuttings were successfully rooted when taken from 3- or 4-year-old white pines between mid-July and mid-September, treated with growth substances, and placed in shaded glass-covered cutting beds. Older trees and untreated trees did not root so well. Root pruning appears necessary to stimulate a well-branched root system.

Wilde, S. A. 1941. **A balanced diet for nursery stock.** Better Crops with Plant Food 25 (6): 14-16, 40-42, illus.

A brief discussion of the role of soil nutrients in seedling growth and nursery soil management. From thousands of virgin forest soil analyses, standards or optimum levels and balance (balance emphasized) for nursery soil nutrients are presented with a general statement of how these standards can be met in nursery practice.

SEEDING AND PLANTING

Allen, John C. 1953. **A half century of reforestation in the Tennessee Valley.** Jour. Forestry 51: 106-113.

Of some 170 million trees planted up to 1946, more than 5 million were white pine. Under average conditions, the early height growth of white pine compares favorably with that of the five other major species used. All of these species except yellow-poplar (which does best in shales) grew best on granitic soils with some ground cover. White pine is the preferred species to plant within its natural range on granitic soils and on shales where there is little or no erosion.

Baldwin, H. I. 1938. **Comparison of planting in ploughed furrows and unbroken sod.** N.H. Forestry and Recreation Comn., Fox Forest Notes 5, 1 p.

Planting in furrows was easier, and showed better survival and better height growth over 9 years, than planting done in unbroken sod on abandoned fields. White pine, white spruce, red spruce, and red pine were planted.

Baldwin, H. I. 1938. **Comparison of spring and fall planting.** N.H. Forestry and Recreation Comn. Fox Forest Notes No. 8, 1 p.

Tests made in 1 year indicate that spruces and white pine can be planted in late September at Hillsboro with good survival and even better initial growth than from spring planting.

Baldwin, Henry I. 1938. **Planting experiments in the Northeast.** Jour. Forestry 36: 758-760.

Experiments in the Northeast have shown that white pine survival and growth were best when the stock was fall-planted. White pine planted with the slit method made considerably better growth and had somewhat better survival than those hole-planted. Better growth was made by 3-0 stock than by 2-2 stock.

Baldwin, H. I., and G. M. Hopkins. 1941. **Course of seasonal height growth in summer planted white pine.** N.H. Forestry and Recreation Comn., Fox Forest Notes 25, 1 p.

The trees were taken from cold storage and planted on July 17, when white pine has normally completed more than 90% of its height growth. These trees completed 95% of their height growth in 3 weeks and, though the entire growing period was much shortened, the growth curves still conformed well to the typical normal growth curve of this species.

Baldwin, Henry I., and Alfred Pleasonton. 1952. **Cold storage of nursery stock.** N.H. Forestry and Recreation Comn. Fox Forest Notes 48, 2 pp.

Three-year old seedlings, lifted in the fall and spring, were stored in deep-freeze lockers, meat-storage vaults, and in a cool cellar. After planting in April, June, and July, these results were recorded: fall-lifted trees had a lower survival than those spring-lifted; best survival was obtained with trees from the meat-storage vault; white pine withstood storage better than the other species.

Bramble, William C. 1952. **Reforestation of strip-mined bituminous coal land in Pennsylvania.** Jour. Forestry 50: 308-314, illus.

During 5 years of 100-tree test plantings with many species it was found that early survival of white pine was 40% or better on acid yellow-brown and blue shale and on acid sandstone mixed with shale. It was 35% in 3 plantings on very acid, thin-bedded, carbonaceous shale. The minimum survival that could be described as adequate was 40%.

Brooks, Henry. 1900. **Planting white pine seedlings.** Amer. Forestry Assoc., The Forester 6: 169.

White pine seedlings may be potted in paper pots and can be set out in the field at the rate of 100 per hour. If well-watered and kept in the partial shade of an orchard, for instance, the seedlings can be kept in good condition throughout the year. This method is suggested for those who are planting small areas and find it more convenient to plant throughout the year rather than concentrating the work in the spring.

Burns, G. P., and E. S. Irwin. 1942. **Studies in tolerance of New England forest trees. XIV. Effect of spacing on the efficiency of white and red pine needles as measured by the amount of wood production on the main stem.** Vt. Agr. Expt. Sta. Bul. 499, 28 pp., illus.

A detailed study using 28-year-old white and red pine trees initially spaced 2 x 2 and 4 x 4 feet on a level uniform site. Samples of 10 to 16 trees were cut May 1941, needles removed, and stems sectioned. Results show that tree d.b.h. was 48 and 16% greater on the 4 x 4 spacing than the 2 x 2 for red and white pine respectively. A highly significant correlation was found between the volume increment of 1940 on the main stem and needle development in terms of dry weight, numbers, surface area, or cubic volume.

Chapman, A. G., and R. D. Lane. 1951. **Effects of some cover types on interplanted forest tree species.** U.S. Forest Serv. Central States Forest Expt. Sta. Tech. Paper 125, 15 pp.

In connection with some hardwood planting tests on old fields in Ohio, white, pitch, and shortleaf pines were planted pure and in mixture with black locust. After 12 years the survival of white pine was good, but total height was only 10.5 feet in the mixed planting compared to 24 feet in the pure. Pitch and shortleaf pines did not survive in the mixed planting.

Coolidge, Philip T. 1911. **Silvicultural treatment of abandoned pastures in southern New England.** Forestry Quart. 9: 253-261, illus.

From published yield figures and general observations on pasture conditions, it appears profitable to open holes in juniper and redcedar stands to plant white pine.

DenUyl, Daniel. 1951. **From field to forest—a 50-year record.** Jour. Forestry 49: 698-704.

In nearly 50 years of experience with forest planting on the Clark State Forest in Indiana, seeding and planting of hardwoods has been generally unsuccessful, and the earliest plantings of softwoods have also been unsuccessful. However, white pine planted under hardwood plantations have survived and developed well. These stands required release from hardwoods and have been thinned and pruned.

Fernow, B. E. 1917. **Axton plantations.** Jour. Forestry 15: 988-990.

In the absence of an official record of the establishment of the plantations, these notes were prepared as a brief record of conditions at the time of planting. Most of the planting stock was white pine, Scotch pine, and Norway spruce. The plantings were made under 14 different conditions during the period 1898-1903.

Fraser, J. W. 1952. **Seed-spotting of conifers under a mixed hardwood stand.** Canada Forestry Branch Silvic. Leaflet 67, 3 pp.

This experiment indicates that seed-spotting of white spruce, white pine, or red pine under thinned 50-year-old white birch-aspen-red maple stands is not likely to succeed unless competition from less desirable species is controlled by cleanings, chemical spraying, or other means. After 26 years, white pine survival was only 11% and average height was only 1.4 feet with a maximum height of 5.8 feet.

Haasis, F. W. 1914. **Results of an experiment on the effect of drying of the roots of seedlings of red and white pine.** Forestry Quart. 12: 311-318.

Bare-rooted planting stock was exposed to full sun on a board for various lengths of time and then planted. The test was a small one but it is perhaps safe to say that such exposure for a period of 2 hours in the morning is not necessarily fatal. Red pine seems to have been more affected than white pine.

Hart, A. C. 1954. **Hardwoods now predominate on burn at Centerville, Maine.** Jour. Forestry 52: 360-361.

An area in southern Maine that was burned by a hot fire in the fall of 1947 was seeded from the air with white pine in March 1948. The succeeding summer season was very dry and by 1950 the seeding was judged a failure. In 1952 the area was well stocked with aspen, birch, and red maple, under which there was a moderate amount of spruce but little fir or pine.

Hetzel, J. E. 1941. **Forest plantations in northwestern Pennsylvania.** U.S. Forest Serv., Allegheny Forest Expt. Sta. Occas. Paper 3, 5 pp., illus.

Some 73 plantations of the most commonly planted species (including 13 plantations of white pine) were scored, at about 20 years of age, on height growth, diameter growth, and form of individual trees. White pine had the lowest score on each criterion. Despite the former value of white pine in this region, the author does not recommend the species. Slow early growth; competition from faster-growing species; severe damage by the white-pine weevil, browsing by deer, rabbits, and domestic stock; and infection by blister rust all combine to give poor survival and inferior form to white pine plantations.

Hicock, Henry W. 1942. **The rainbow forest plantations.** Conn. Agr. Expt. Sta. Bul. 464: 619-702, illus.

About 120 acres of experimental plantings have been made at Windsor and East Granby, Conn.—most of them with white pine. The soil is a deep Merrimac coarse sand. On the basis of these plantings, it is recommended that white pine be planted in pure groups in openings surrounded by cover 25 feet or more high; or establish two-aged stands by first planting any fast-growing species, to be followed by white pine in 5 to 10 years. The mixture should be by groups of 30 to 50 trees. The overstory should be gradually removed beginning about 10 years after white pine is planted.

Kemptom, Harold B. 1903. **The planting of white pine in New England.** U.S. Bur. Forestry Bul. 45. 40 pp., illus.

This early discussion emphasizing planting results is based primarily on examination of some older plantations for which summaries of history, condition, and growth are given. Concludes that planting is profitable for the small landowner on rotations of 40 years or longer.

Lake States Forest Experiment Station. 1930. **Germination and survival of conifers under aspen.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 28. 1 p.

Some 32 days after sowing Norway pine, white pine, and white spruce in prepared seed spots, there were white pine seedlings in 26 out of 50 spots where the aspen overstory was clear-cut, in 4 out of 50 where 35% of the aspen stand was removed, and in only 2 out of 50 where the aspen overstory was uncut. The differences are probably due to the higher soil temperatures in the cut plots.

Lake States Forest Experiment Station. 1935. **Prolonged exposure of roots causes death of planting stock.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 96. 1 p.

In the severe climatic conditions of a drought machine, the roots of 1-1 white pine, Norway pine, jack pine, and 2-0 white spruce were damaged after only 10 minutes' exposure; exposures of more than 15 minutes may eventually prove fatal. Exposures of 5 to 6 hours completely killed the planting stock.

Logan, K. T. 1951. **Seed-spotting in a cut-over jack pine stand.** Canada Forestry Branch. Silvic. Leaflet 57, 2 pp., illus.

Regeneration by seed-spotting was tested on a dry medium site from which was clear cut a mature stand of jack pine with an understory of red and white pine. Less than 40% of the white pine spots were initially successful and 7 years later all of the white pine had died.

Logan, K. T., and J. L. Farrar. 1953. **An attempt to grow white pine under an aspen stand.** Canada Forestry Branch Silvic. Leaflet 77, 3 pp.

Underplanting white pine in a young aspen stand on fresh to very moist sites was unsuccessful because of mortality caused by grazing, blister rust, and suppression by hazel *(Corylus cornuta)*, wild raisin *(Viburnum cassinoides)*, mountain holly *(Nemopanthus mucronata)*, and aspen. Best survival was less than 10% and best growth was only 9 feet in 13 years.

Maissurow, D. K. 1939. **Mixed group planting on the Nicolet National Forest.** Jour. Forestry 37: 853-855.

Jack, red, and white pines and other conifers have different cover requirements in early stages of growth after planting. On areas that had uniform site but lacked uniform cover, two or three species of different cover requirements were mixed in groups, the size and location of which were determined by the density of protective vegetation. Survival and growth of planted seedlings appeared to be favored by this method compared with planting one species only, and the cost per acre of plantation establishment was relatively lower for mixed-group planting.

Maki, T. E., H. Marshall, and C. E. Ostrom. 1945. **Effects of naphthaleneacetic acid-sprays on the development and drought resistance of pine seedlings.** Bot. Gaz. 107: 297-312.

Seedlings of white pine were sprayed in September, October, and March with various concentrations of naphthaleneacetic acid in 1% Dowax emulsion. Other seedlings were top-pruned. All treatments were an attempt to inhibit growth and increase resistance to drought. White pine was not affected by the growth-regulator treatments.

Marshall, Hubert, and T. E. Maki. 1946. **Transpiration of pine seedlings as influenced by foliage coatings.** Plant Physiol. 21: 95-101, illus.

In a test of foliage coatings on three pine species to reduce transpiration and lessen drought killing, 30 seedlings were lifted from the nursery, potted in fine moist sand, and exposed to artificial drought conditions for a 5-day period. The top-dipped specimens transpired 40% less than the untreated controls during the first 4 days of drought. Higher temperature and lower relative humidity during the fifth day severely injured white pine controls and increased water loss of treated plants. Water loss was shown to vary directly as the fresh weight of the seedling in both controls and coated samples.

Merz, R. 1951. **Comparative survivals and costs of plantations by different methods of ground preparation and planting.** U.S. Forest Serv. Central States Forest Expt. Sta., Sta. Note 64. 2 pp.

Experiments on old fields in southeastern Ohio showed little difference in first- or second-year survival of white and red pine when different methods of ground preparation and planting were used. Machine-planting with no ground preparation was the cheapest method, and planting by the mattock method in scalps the most expensive.

Minckler, Leon S. 1941. **Planting white pine in laurel and rhododendron "slicks."** Jour. Forestry 39: 1036.

Several methods of site preparation were tried. It was most efficient to cut back the thickets in strips or holes with widths either equal to or three-quarter of the height of the thicket. The spacing and arrangement of the prepared sites and of the pines within the sites depended upon the height of the thicket. Under these conditions, 80% survival and 2 feet of total height may be expected of white pine 5 years after planting.

Morey, H. F. 1935. **A success index for young forest plantations.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 16, 3 pp., illus.

Presents alinement charts for judging success of young white, red, and Scotch pine and Norway spruce plantations on the basis of survival, total height, and age. Plantations may be compared to each other with a relative success index, or their height may be compared with the averages on which the charts are based.

Paton, R. R. 1927. **Mixed vs. pure forest plantations.** Ohio Agr. Expt. Sta. Bimo. Bul. 12: 18-20.

Mixed plantations are practical and their advantages of protection outweigh the disadvantages. White pine can be successfully planted in mixed plantations with sugar maple, yellow-poplar, or red pine, the choice depending upon the site.

Polivka, J. B., and O. A. Alderman. 1937. **The problem of selecting the desirable pine species for forest planting in Ohio.** Jour. Forestry 35: 832-835.

Selections should be based on growth rate and susceptibility to insects of local occurrence. Mixed planting may cause reduction of insect damage. The most desirable species to plant (in order) are: white, jack, Norway, and shortleaf pines. The principal enemies of white pine in this area are the pine bark adelges, the Pales weevil, and the leaf feeder *Pachystethus oblivia* Horn.

Schantz-Hansen, T. 1932. **A comparison of the results obtained with forest-pulled and nursery-grown planting stock in northern Minnesota.** Jour. Forestry 30: 406-408.

Forest-pulled stock of white and red pine can be used on some areas with a reasonable degree of success. Nursery stock is superior but not so much as might be expected. Apparently some overhead shade is as beneficial to the forest-pulled stock as it is to other kinds.

Schantz-Hansen, T. 1945. **The effect of planting methods on root development.** Jour. Forestry 43: 447-449.

When 2-2 stock of white, red, and jack pine and white spruce was planted in sandy soil, the method of planting did not seriously affect either survival or root development.

Shirley, Hardy L., and Lloyd J. Meuli. 1938. **Influence of foliage sprays on drought resistance of conifers.** Plant Physiol. 13: 399-406.

Drought resistance of red and white pine and white spruce was not increased by beeswax, beeswax-parawax, rubber solution, or hydrowax foliage sprays. Tests were conducted in a drought machine.

Stafford, Earle. 1931. **Skeleton planting.** Jour. Forestry 29: 41-47.

Describes the various plant successions on good and poor sites on abandoned meadows, pastures, and cutover land in southwestern Massachusetts, and the resultant increase of soil fertility. The author proposes "skeleton planting" of conifers (300 trees per acre instead of 1,200) as being cheaper to start with and productive of more and better timber in the end. Disadvantages are also discussed.

Stoeckeler, Joseph H. 1947. **Planting poorly-drained wet sites.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 276, 1 p.
Planting in three plowed furrow positions on poorly drained silt loams and stiff silty clays was tested with five species. Survival and growth of white pine was uniformly poor.

Stoeckeler, J. H. 1950. **How long can conifers be held in spring by cold storage?** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 343, 1 p.
Jack, red, and white pine and white spruce trees were lifted on May 3 and stored at 50° F. for 1, 2, 3, 4, and 5 weeks respectively before transplanting in Wisconsin. Trees were also lifted at weekly intervals from May 3 to June 7 and transplanted immediately to determine the effect of late transplanting. Prolongd cold storage before transplanting reduced seedling vigor and size of trees at end of first year by shortening the favorable season for growth. Late transplanting, with or without cold storage, had an adverse effect on growth, which was accentuated by long storage.

Stoeckeler, J. H., and G. A. Limstrom. 1950. **Reforestation research findings in northern Wisconsin and upper Michigan.** U.S. Forest Serv. Lake States Forest Expt. Sta., Sta. Paper 23, 34 pp., illus.
This report supplements Rudolf (1950) with information derived from various experimental plantings, totalling 490 acres. Discusses in detail the best available methods for reforestation, emphasizing planting sites. A planting-site classification shows, for different combinations of soil texture, soil drainage, overhead cover, and ground cover, the recommended species and size of planting stock. Release from hardwood competition is also discussed.

Stoeckler, J. H., and A. W. Sump. 1940. **Successful direct seeding of northern conifers on shallow water-table areas.** Jour. Forestry 38: 572-577.
Fair results were obtained with white pine where the water table was 1.5 to 5 feet below the surface. Partial stands may be obtained where the water table is deeper. The seed should be sowed between the middle of April and the second week of May.

Trenk, F. B. 1948. **Influence of planted tree belt in Plainfield sand on erosion control and moisture conservation.** Iowa State Col. Jour. Sci. 22 (4): 449-461.
An experimental 8-row shelterbelt composed of conifers and hardwoods was established between 1928 and 1932 on a field of Plainfield sand. Abnormal heat and drought during the first five growing seasons caused high mortality in the initial plantings. Conifers (including white pine) averaged 17 feet high when 10 years old; they were effective in trapping snow and protecting soil and crops from the prevailing wind. Cultivation for the first 5 years after planting stimulated tree growth moderately.

Tryon, Henry H. 1932. **A study of several coniferous underplantings in the upper Hudson highlands.** Black Rock Forest Bul. 3, 27 pp., illus.
White pine, planted under a cordwood-size stand of oak, chestnut, and maple, was less than 2 feet high at 10 years compared to 12 feet on the same site when open-grown. Similar comparisons are made for Scotch and Norway pine, larch, and Norway spruce. Both in the open and under the overstory, white pine was the slowest growing species. Coniferous underplantings cannot be successfully brought to maturity without subsequent cultural treatment.

Wahlenberg, W. G., and W. T. Doolittle. 1950. **Reclaiming Appalachian brush lands for economic forest production.** Jour. Forestry 48: 170-174, illus.

A number of tests demonstrated that white pine can successfully replace laurel and rhododendron thickets. If planted in holes as wide as the height of thicket (if less than 3 feet high) or in lanes equal in width to three-quarters the height of the thicket, white pine will be free of competition in about 6 years. These openings can be prepared by cutting back or bulldozing the thicket. Openings made by fire or logging can also be used.

Wappes, L. 1941. **Erfahrungen über Freisaaten.** Deut. Forstwirt 23 (77/78): 581-583.

Broadcast sowing of white pine has been successful under fairly heavy shade, using seed at the rate of 1 kilogram per hectare, preferably with an admixture of silver fir seed. The author concludes that, in general nothing can be expected of seedlings if there is a heavy growth of grass.

Westveld, Marinus. 1949. **Airplane seeding: a new venture in reforestation.** Soc. Amer. Foresters Proc. 1948: 302-311, illus.

Describes methods and equipment used to reseed a burned-over white pine area on the Massabesic Experimental Forest near Alfred, in southern Maine. Ground checks showed satisfactory seed distribution.

Ziegler, E. A. 1915. **Further notes on the effect of exposure on white pine seedlings.** Forestry Quart. 13: 163-170.

Data are presented on the amount of drying out in white pine seedling planting stock on calm sunny days, calm cloudy days, and sunny days with a high wind. The length and season of exposure (lying on the ground) were varied, and unexposed check trees were also recorded. No attempt was made to interpret the data.

STAND IMPROVEMENT : HARVEST CUTTINGS NATURAL REGENERATION

Anonymous. 1950. **Forest practice standards for New Hampshire woodlands.** Univ. N.H. Ext. Bul. 98, 16 pp.

An interpretation of the forest-practice standards that serve as a basis for yield-tax abatement under the New Hampshire forest tax law. In pine stands, good practice consists of group or individual tree selection cutting, the openings usually not to exceed ¼ acre. In larger stands, strip cuttings or a combination of strips and the above are good practices. Clean cuttings are occasionally good practice in older pine stands where young growth has become well established. Provision is made for special cases.

Anonymous. 1953. **New Hampshire guides for improvement cuttings in immature stands.** Univ. N.H. Ext. Folder 26, 4 pp.

Guides used to judge the acceptability of improvement work under the Agricultural Conservation Program. An acre of unmerchantable stand containing 150 to 800 red or white pine crop trees 2 inches d.b.h., or the equivalent, may be improved by removal of competing hardwoods. How to do the work is discussed briefly. The costs should be between $8 and $25 per acre.

Baldwin, H. I. 1950. **Damage to advance reproduction in selective logging.** N.H. Forestry and Recreation Comn. Fox Forest Notes 46, 2 pp.

Selective cutting in a pine-hemlock stand, if done carefully, can conserve two-thirds to three-fourths of the advance conifer reproduction. Greatest injury occurred among trees 4 to 5 feet high. Small seedlings can be protected best if logging is done on snow. Hemlock was least susceptible to damage, white pine the most susceptible, and spruce intermediate.

Bertram, John. 1898. **The reproduction of white pine in North America.** Mich. Polit. Sci. Assoc. Pub. 3 (4): 121-125.

General observations on the reproduction of white pine and the way in which stands of overmature pine, mixed pine and hardwoods, and dense pine stands should be cut. In the latter two cases, clearcutting and burning is recommended.

Brown, R. M., and H. D. Petheram. 1926. **The conversion of jack pine to red and white pine.** Jour. Forestry 24: 265-271.

Jack pine invades sites originally occupied by better species and unless controlled becomes the dominant type on the lighter soils. This is one of the main management problems on the Minnesota National Forest. Studies of white pine and red pine reproduction were made in jack pine stands clearcut and uncut, but of various densities. Clearcutting perpetuates jack pine. Where seed trees are present, partial cutting will bring in red and white pine. A light cut will reduce the proportion of jack pine.

Burnham, C. F., M. J. Ferree, and F. E. Cunningham. 1947. **The white pine-oak forests of the Anthracite Region.** U.S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 8, 35 pp., illus.

The white pine-oak forests occupy a fifth of the forested area in Pennsylvania's Anthracite Region, but because of heavy cutting and fires they are in poor condition. Suggests measures needed to improve the productivity of these forests, and especially to increase the dwindling proportion of white pine.

Burnham, C. F., M. J. Ferree, and F. E. Cunningham. 1947. **The white pine-hemlock forests of the Anthracite Region.** U.S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 11, 25 pp., illus.

White pine-hemlock forests, found chiefly on well-drained slopes and along ravines, occupy less than 8% of the forest area in the Anthracite Region of Pennsylvania, but they contain 29% of the volume in saw-timber stands. Even so, they produce only half of what they could. Silvicultural treatments to improve the stands and to increase the proportion of white pine are suggested.

Burns, George P. 1933. **The effect of thinning on white pine reproduction.** Vt. Agr. Expt. Sta. Bul. 354, 24 pp.

From studies in two white pine stands on sandy soil near Burlington, Vt., it is concluded that white pine cannot be reproduced by natural methods or by any of the grades of thinning in practice. Under all conditions of thinning, a birch-red maple forest is the immediate result. But, when a thinned area is heavily pastured, the cattle keep down the hardwoods and white pine will dominate the reproduction. Where similar areas were planted, white pine in almost pure stands resulted.

Cary, Austin. 1924. **Notes from the white pine country.** Jour. Forestry 22: 49-52.

Observations in southwestern Maine on three white pine lots clearcut in the winters before, during, and after a seed year. The resulting reproduction is hardwood on the first, dense pine on the second, and well-stocked pine with some hardwood on the third. This points up the importance of making clearcuttings in seed years.

Chapman, Gordon L. 1954. **Cutting weed hardwoods increases woodlot yields.** Maine Univ. Forestry Dept. Tech. Note 30, 2 pp.

When weed hardwoods overtopping 700 to 1,000 spruce, fir, pine, and hemlock per acre on softwood sites can be cut profitably at 30 to 40 years of age, the additional released softwood growth can be looked upon as clear profit. If hardwood markets are not available the 500 hardwood weed trees per acre, averaging 4 inches in diameter, could be poisoned at a cost of $10 to $15 per acre. Allowing $3.50 per cord as a stumpage value of softwood pulpwood, this investment in stand improvement should be repaid by additional growth in 7 to 10 years.

Chapman, G. L., and N. W. McGowan. 1954. **A comparison of five commercially clear-cut white pine stands in southern Maine eight to thirteen years after cutting.** Maine Univ. Forestry Dept. Tech. Note 34, 5 pp.

Commercial clearcutting resulted in a relatively permanent forest type change in one instance and only minor and temporary changes in the other four. In three cases, however, it resulted in stands that will produce much lower yields in quantity and quality during the next rotation than could rightly be expected unless the situation is corrected by application of weedings and/or improvement cuttings in the near future.

Chapman, H. H. 1948. **(A review of) Red pine management in Minnesota.** Jour. Forestry 46: 775-778.

Primarily a discussion of regeneration of red pine with particular emphasis on the use of fire in regenerating both red and white pine. It is noted that a fire, just before seedfall, is the natural and most effective method of regenerating these species. (See also Eyre and Zehngraff, 1948).

Chapman, H. H. 1951. **More about pines and fire.** Jour. Forestry 49: 285-286.

It is noted that many years ago Fernow (1905), Zon (1912), and Frothingham (1914) published statements to the effect that properly timed and controlled fires can play a major part in obtaining reproduction of both red and white pine. The author's observations confirm these views.

Cline, A. C. 1924. **The group selection method with white pine.** Jour. Forestry 22: 128-134.

Cites the financial and silvicultural advantages gained by group-selection cutting beginning before the entire stand is merchantable, as compared to clearcutting. The woodlot is left in better condition for growth. Over a period of 23 years the group-selection method would have produced a profit four times as large as the investment, whereas the clearcutting would barely yield double the investment based on an operation on the Harvard Forest.

Cline, A. C. 1929. **Forest weeding, with special reference to young natural stands in central New England.** Mass. Forestry Assoc. and Harvard Forest, 19 pp.

States that weeding is the most profitable woods treatment. Detailed instructions are given for weeding various types of young stands. In general, the first weeding should be made 4 to 8 years after clearcutting. White pine and the better hardwoods should be released at the rate of 150 to 200 trees per acre. Only the stems overtopping the crop trees should be cut, leaving the rest as stand fillers. Weeding should be heavier in stands that follow clearcutting of hardwoods. White pine especially should be released in groups rather than as single stems.

Cline, A. C., and H. J. MacAloney. 1931. **A method of reclaiming severely weevilled white pine plantations.** Mass. Forestry Assoc. Bul. 152, 11 pp., illus.

Even severely weevilled plantations usually contain many codominant and intermediate white pines that are not badly deformed. About 200 of these per acre can be selected as crop trees. They should be released by girdling (single ax frill) the competing weevilled trees. If the crop trees are 3 to 7 inches d.b.h., they should be pruned to not more than one half their total height. The treatment should be carried out in about three operations at intervals of about 3 years.

Cline, A. C., and H. J. MacAloney. 1933. **Additional notes on the improvement of weevilled white pine plantations.** Conn. Forest and Park Assoc. Pub. 24, 11 pp., illus.

Field studies showed that tree deformation by weevilling is much more severe when the weevil kills two internodes rather than one. It is suggested that the removal of weevilled leaders with the double objective of reducing weevil population and weevil damage may be a profitable undertaking.

Condit, G. R., M. A. Huberman, and John R. McGuire. 1942. **Collect the bounty on your wolf-trees.** Jour. Forestry 40: 680-682, illus.

Wolf-trees are white pines with heavy, wide-spread crowns and other deformities that give them a low product value. Sample strips in pine woodlots in southwestern Maine showed that there were more than six such trees per acre and that they occupied 13% of the area. These wolf trees hold back the growth of straight young trees of good species and potential fast growth. Release of these trees and seedlings can be done profitably by sale of products from the wolf trees.

Cook, David B., and Lawrence S. Hamilton. 1953. **Chemi-peeling pulpwood in New York.** Jour. Forestry 51: 566-569, illus.

Discusses advantages and disadvantages of chemi-peeling and describes the technique of using an ax for the girdle and a bucket and brush to apply the sodium arsenite solution to the girdle. White pine treated in June to early August will show bright foxy-red foliage in 7 to 14 days. The bark will peel well in October and will come off easily the following spring. White pine should be peeled as early as possible to avoid insect damage and blue stain.

Coulter, L. L., and R. A. Ralston. 1954. **Aerial spray tests with 2,4,5-T for scrub oak control in lower Michigan.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Notes 424, 1 p.

Results 2 years after one test and 1 year after another indicate that jack, red, and white pines can be effectively released from scrub oak overstory by an aerial spray in August of 1 pound 2,4,5-T acid equivalent in 2.25 gallons of oil and water per acre. The pines were not damaged by August spraying. Most of the scrub, red, and northern pin oaks, and the scattered red maples, pin cherries, and juneberries were killed.

Downs, Albert A. 1943. **Response of eastern white pine reproduction in the southern Appalachians to liberation.** Jour. Forestry 41: 279-281.

Liberation of eastern white pine reproduction from a decadent hardwood overstory resulted in 17 to 62% greater height growth than on check plots; smaller stems showed greater response. After treatment, damage to pine reproduction by falling limbs or snags was slight. For trees under 11 inches in diameter, poisoning was somewhat more effective than girdling for reducing sprouting of oaks and hickories but not of sourwood, which grew back to menace white pine reproduction.

Egler, F. E. 1949. **Herbicide effects in Connecticut vegetation, 1948.** Ecology 30: 248-256.

The third report on a project at Aton Forest, Conn. Reports early results from the application by various methods of different mixtures and concentrations of 2,4-D, and 2,4,5-T to 116 species. Bark painting, which is cheaper than trunk-wound painting, affected white pine, through complete kill has not yet been verified.

Engle, LaMont C. 1951. **Releasing white pine from oak and aspen.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 346, 2 pp., illus.

As appraised after 8 years, success in releasing white pine from oak and aspen overstorys depends primarily on the height of the pines when released. When 1 foot high and 4 years old, released pines were soon overtopped and needed to be released again. Those 5½ feet high and 19 years old, while sometimes overtopped, are still growing well and should not need another release. Pine 8½ feet high and 22 years old remained above the surrounding sprouts to compete successfuly.

Fisher, R. T. 1918. **The yield of volunteer second growth as affected by improvement cutting and early weeding.** Jour. Forestry 16: 493-506.

After logging, at least 20% of the central-hardwoods region is well stocked with white pine and valuable hardwood reproduction. But these better species seldom are able to compete without help. Many of the older cut-over stands are still dominated by gray birch and aspen after 40 years or more. It is imperative that an improvement cutting be made by the 20th year, and earlier on good sites, if the stand is to yield a substantial percentage of white pine and valuable hardwoods.

Fisher, R. T., and E. I. Terry. 1920. **The management of second-growth white pine in central New England.** Jour. Forestry 18: 358-366.

A brief review of management results on the Harvard Forest and the results of cutting practices on some 54 cut-over pine lots in central New England. Clearcutting in the fall or winter of a seed year is the best and cheapest means of reproducing white pine. Strip and patch cutting have had variable results. Selection cuts are not applicable. The surest method of reproduction is the two-cu,t shelterwood, which has consistently given the best reproduction and is standard practice on the Harvard Forest except in seed years.

Foster, Clifford H. 1954. **The use of silvicides to establish white pine by natural reproduction.** Northeast. Weed Control Conf. Proc. 8: 415-419.

Timely application of the new chemicals shows promise as an economical and satisfactory solution to the competition problem in pine regeneration. An example on the Pack Forest is described in which a poor mixed-hardwood stand is being reproduced to pine from the available seed source. The site was prepared by 2,4,5-T and 2,4-D in oil basal spray of the small advance hardwoods, deadening of pulpwood trees with sodium arsenite, and a heavy cutting of most of the overstory hardwood in a pine seed year.

Fraser, J. W., and J. L. Farrar. 1955. **Strip-cutting in a mixed pine stand.** Canada Forestry Branch Tech. Note 1, 17 pp., illus.

In 1934 a mixed stand of 80-year-old jack pine with a 47-year-old understory of red and white pine was strip-cut in 1- and 2-chain wide strips. One-chain wide strips were left uncut until 1942 when they were partially cut for poles and sawlogs. The sites were considered average for mixed pine. In 1949 and 1950 all areas had at least 60% stocking of white pine reproduction.

Geerinck, Paul A., Willis A. Getchell, and Gordon L. Chapman. 1954. **Response to release of under-planted white and red pine.** Maine Univ. Forestry Dept. Tech. Notes 29, 2 pp.

White pine and red pine planted in alternate rows on a well-drained site under a young birch-maple-aspen stand responded well to a full release made 7 years later. The response of white pine was better than that of red pine. Plots released only lighly or not at all did not show satisfactory growth of pines. Thus, pine should not be planted under such stands until a merchantable cut can be made to release them within a few years.

Hutchinson, Wallace I. 1902. **Treatment of second-growth white pine.** Forestry and Irrig. 8: 319-323, 370-373.

Brief directions for the thinning, pruning, and reproduction of second-growth white pine. Natural stands are generally preferred over planted ones; thinning from below will encourage fastest growth and most rapid turnover of the forest. Pruning should be done carefully with an ax, but not beyond 8 feet. Heavier thinnings beginning about the 30th year will encourage reproduction to replace the stand when it is clearcut in about the 40th year—preferably a seed year.

Littlefield, E. W. 1952. **The pitch pine is dead—long live the white pine!** N.Y. Conserv. 7 (2): 24-25.

A brief discussion of the rehabilitation of pitch pine barrens by the release of natural or planted white pine in the understory. In two examples from eastern New York it is shown that, 4 years after the pitch pine was girdled, the white pine was growing well and was free from weevilling.

Logan, K. T. 1950. **Influence of thinning on reproduction beneath a red and white pine stand.** Canada Forestry Branch Silvic. Leaflet 50, 3 pp.

In this 45-year-old stand on a medium site, thinnings have increased the survival rate of seedlings and resulted in a slight improvement in growth of white pine seedlings. The amount of white pine reproduction has increased only after heavy thinnings, which have not affected reproduction of red pine.

Logan, K. T. 1951. **Effect of seedbed treatment on white pine regeneration.** Canada Forestry Branch Silvic. Leaflet 54, 2 pp.

A 10-year test indicated that seedbed treatment on a medium site under a 55-year-old stand of crown density 70% was beneficial to pine regeneration. With both artificial and natural seeding, a heavy burn, which exposed mineral soil, was very effective, while litter removal by raking and hacking, which exposed mineral soil, was good only when there was sufficient seed (artificial seeding). Light burning was not very successful.

Lutz, R. J., and A. C. Cline. 1947. **Results of the first thirty years of experimentation in silviculture in the Harvard Forest, 1908-1938. Part I. The conversion of stands of old field origin by various methods of cutting and subsequent treatments.** Harvard Forest Bul. 23, 182 pp.

Discussion of a series of case histories, mainly of old-field white pine, grouped according to soil characteristics. These experiments showed that pine would be very difficult to maintain, so later weeding and thinnings favored the better hardwoods rather than the pine. Better stands might have resulted had this practice been started earlier.

McKinnon, F. S., G. R. Hyde, and A. C. Cline. 1935. **Cut-over old field pine lands of central New England.** Harvard Forest Bul. 18, 80 pp., illus.

Some 226 stands in central Massachusetts and southern New Hampshire were examined to determine the relations between present stand conditions and the character of the preceding old-field pine stand, site quality, and other items of stand history. The silvicultural aspect of the results are discussed and recommendations are given for various situations.

Miller, William D. 1934-35. **The effect of weeding on the survival and growth of white and red pine.** Jour. Forestry 32: 1021-1022; 33: 87.

Plantations set out in 1916-17 were weeded 2 to 8 years later; the results in 1931 are given. White pine survival was not affected, but growth was increased 75 to 200% in diameter and 35 to 50% in height, despite heavy weevilling after the weeding.

Morton, Nathaniel. 1898. **Fixing up a woodlot in Massachusetts; trimming white pine.** Forester 4: 125-127, 145-146.

Discusses early experiences with pruning, weeding, and growth of white pine in Plymouth, Mass. Pruning was best done with an ax or drawshave, cutting into the bark all round the knot. Oak stumps may be killed by pounding the frozen sprouts in winter about 4 years after cutting. Hardwood covers should be left for pine seedlings until they are 4 years old but then should be removed. A tract handled in this way became well stocked with thrifty young white pine.

Northeastern Forest Experiment Station. 1945. **Guide for cutting eastern white pine.** U.S. Dept. Agr. AIS-7, 8 pp., illus.

Guide for merchantable stands (2,000 board-feet per acre cut) in which at least half the trees 6 inches d.b.h. or larger are white pine. Not more than 60% of the merchantable volume should be cut. The remaining stand should contain (about 40 feet apart) some trees 10 inches d.b.h. or larger. Another cut can be made in 15 years. Several log rules are supplied and simple cruising methods are described.

Robertson, W. M. 1945. **Succession cutting in pine.** Canada Forestry Branch Silvic. Res. Note 74, 8 pp.

At Petawawa Experiment Station a 70-year-old overstory of jack pine was removed to release the succession stand of young (37 years old) white and red pine. Diameter growth was greatly stimulated; height growth was slightly retarded. Volume growth increased from 1.1 to 4.5%; this large increase occurred almost entirely in immature red and white pine, the jack pine being unaffected. Much more important is the improvement in quality increment, from the transfer of growth from mature jack pine to immature white and red pine.

Robertson, W. M. 1946. **Selection cutting in pine.** Canada Forestry Branch Silvic. Res. Note 80, 6 pp.

This study was undertaken to evaluate the effects of selective cutting to crown densities of 80, 40, and 20% and clearcutting in strips in a two-aged stand of jack, white and red pine where the overstory, mainly jack pine, was overmature. Records were taken on a series of seven permanant sample plots over a period of 6 years. It would seem that succession cutting is the most desirable method of treating such two-aged stands.

Sarles, R. L. 1953. **Chemical bark peeling of white pine by applying sodium arsenite in September.** Ohio Agr. Expt. Sta. Forest Mimeo. 4, 2 pp., illus.

In a small-scale test white pine was successfully treated with sodium arsenite as late as September 24. Complete separation of the bark from the wood was obtained within 4 months of treating.

Schantz-Hansen, T. 1937. **The response to full release of white pine planted under jack pine.** Jour. Forestry 35: 263-265.

An open jack pine stand on very light soil was underplanted with white pine spaced 6 x 6 feet. Survival was good and 11 years later the white pine averaged about 4 feet in height. At that time the jack pine was cut from part of the area. The white pine showed response to release the third year after cutting. Ten years after release, the white pine averaged 13.6 feet high, and 50% of the trees were weevilled. On the uncut plot, the white pine was 10.7 feet high but only 8% of the trees were weevilled.

Smith, David M. 1951. **The influence of seedbed conditions on the regeneration of eastern white pine.** Conn. Agr. Expt. Sta. Bul. 545, 61 pp., illus.

This comprehensive report shows that few seedlings die from deficient soil moisture. The author concluded that regeneration was best where there is a minimum of direct light and a maximum of diffused light reaching the forest floor. Once established, seedlings grow well only in full sunlight.

Smith, Lloyd F. 1940. **Factors controlling the early development and survival of eastern white pine in central New England.** Ecol. Monog. 10: 373-420, illus.

Germination, survival, and early growth of white pine seedlings were studied experimentally on similar sites under white pine stands representing full shade, and full light conditions. Solar radiation, surface temperature, soil temperature, and soil moisture were important to seedling development and were most affected by stand conditions. Concludes that shelterwood or small group cuttings with slash and litter dispersal are the best ways to regenerate white pine in New Hampshire.

Society of American Foresters, New England Section. 1944. **Recommended forest practice standards for New England.** Jour. Forestry 42: 716-725.

The forests of the white pine-transition hardwoods region vary widely as to stocking and composition. They are generally in a depleted and deteriorated condition caused by cuttings, fires, and insect and disease depredations during the last 50 years. Recommends that some form of partial cutting be the standard practice for this region.

Society of American Foresters, New England Section. 1930. **(Comments on) Report of the committee on the improvement of composition of stands with special reference to release cuttings.** Jour. Forestry 28: 1164.

The committee argues that release cutting offers the most profitable field in silvicultural operations. Girdling hardwoods increased growth on the spruce or pine under them; girdling worthless hardwoods to increase growth on merchantable softwoods promised the best financial returns. Where there is an adequate number of crop trees, release cutting (either weeding or girdling) will produce a more acceptable stand at less cost than planting.

Spaeth, J. Nelson. 1922. **Notes on the release of white pine in Harvard Forest, Petersham, Mass.** Jour. Forestry 20: 117-121.

On abandoned farmlands in central New England, white pine must compete with hardwoods that not only shade out the pine but also hinder growth by whipping the pines' terminal and lateral buds. Red maple is the worst competitor. Recommends release cuttings between 10th and 25th years to favor pines.

Stickel, Paul W. 1930. **Artificial vs. natural replacement on blight-killed chestnut land.** Jour. Forestry 28: 572-573.

Studies of sample plots on typical land where chestnut was blight-killed indicate that artificial replacement of the chestnut with white pine has been successful within 10 years. On plots where replacement has been natural, less than half the stand has commercial value. Weeding aids materially in the growth of planted stock.

Stoeckeler, Joseph H. 1947. **When is plantation release most effective?** Jour. Forestry 45: 265-271, illus.

Tests of the release of white, red, and jack pine in the Lake States showed a marked advantage in cutting aspen suckers and sprouts in late June, or just after the leaves attain full growth. The effective period continued to early August. Cuttings made in winter or early spring resulted in higher densities and more vigorous sprouts. Cutting in summer (one cut) saved at least one release operation in pine plantations.

Swain, Lewis O. 1954. **Economical tree killing.** N.H. Univ. Agr. Expt. Sta. Bul. 408, 15 pp., illus.

Small blotting-paper tabs containing about ½ gram of sodium arsenite are effective and economical tree killers when inserted in a pocket between the bark and the wood of the tree. A small peeling spud used to make the pocket is described. White pine is easy to kill and may be treated in any season.

United States Forest Service. 1945. **Proposed guides to minimum forest practices.** U.S. Forest Serv. Region 9, 17 pp.

Includes guides for red and white pine types of the Lake States: desirable residual stocking levels and cutting intensities for stands less than 125 years old and for stands more than 125 years old. Adequate levels of stocking for reproduction on cut-over lands are given.

Young, Leigh J., and Francis H. Eyre. 1937. **Release cutting in plantations of white and Norway pine.** Mich. Acad. Sci. Arts and Letters, Paper 22: 301-320.

Studies in Michigan and Minnesota indicate that white pine benefits during early years from overhead shade, especially on dry sandy soils, but to insure good growth, should be released as soon as it is well established. Response is prompt and roughly proportional to the degree of release. But a clearcutting of the overstory will overexpose suppressed pines and afford no protection against the white-pine weevil. Prolific sprouting in cut stands will destroy the underplanted white pine.

THINNING : PRUNING

Anonymous. 1930. **Much-thinned pine stand superior in volume.** U.S. Forest Serv. Forest Worker 6 (5): 17.

A 47-year-old stand of northern white pine at Durham, N. H., that had been thinned annually for the last 18 years had a greater volume than a comparable unthinned stand containing more than twice as many trees. Average annual diameter growth was twice as great in the thinned stand as in the unthinned stand and the trees were taller, of better quality, and more thrifty.

Adams, W. R., and M. R. Schneller. 1939. **Some physiological responses to close pruning of northern white pine.** Vt. Agr. Expt. Sta. Bul. 444, 26 pp., illus.

Only 13.6% of the dead branches pruned through the branch base showned callus formation on the face of the pruned stub, but this was six times the number when the branch base was not cut. When living branches were cut through the branch base the initial callus response was nearly perfect but less than 20% of the stubs showed callus when the branch base was uninjured. The cell composition of the callus and changes during formation are described. Recommends pruning with pruning saw and ladder (if necessary) between October and June for best healing.

Adams, W. R., and G. L. Chapman. 1942. **Competition in some coniferous plantations.** Vt. Agr. Expt. Sta. Bul. 489, 26 pp.

The 28-year-old plantations examined included some white pine planted at three densities (2 x 2 feet to 8 x 8 feet) on poor loamy sands in the Champlain Valley. White pine grew satisfactorily on this site and expressed dominance even in the densest stands, but adequate thinning to reduce competition is essential for the production of crop trees with good form and maximum wood volume.

Barrett, Leonard I., and Albert A. Downs. 1943. **Growth response of white pine in the southern Appalachians to green pruning.** Jour. Forestry 41: 507-510.

In a test of three degrees of pruning with 376 trees it was found that about 30% of the number of living whorls may be pruned without seriously reducing height or diameter growth; and that smooth flush cuts without splinters or breaks are important for rapid healing and quick production of clear lumber. The trees used in this test ranged from 2 to 7 inches d.b.h.

Behre, C. E. 1932. **Change in form of red spruce after logging and of northern white pine after thinning.** Jour. Forestry 30: 805-810, illus.

Young even-aged stands of white pine that have been heavily thinned from below generally show an average increase in form quotient. The change of form after cutting is closely correlated with the form quotient at time of cutting.

Bickerstaff, A. 1942. **The size of tree in pruning.** Canada. Dept. Mines and Resources, Dom. Forest Serv. Cilvic. Leaflet 9, 2 pp.

If trees are pruned when small (3 to 4 inches in diameter), pruning will be easier, scars will occlude more rapidly, and a greater proportion of clear lumber will be produced in the butt log in a given time or at a given size than if pruning is deferred. The practice at Petawawa is to prune to 7 feet, then 12 feet, and finally to 17 feet in three operations, keeping the knotty core to about 4 inches in diameter.

Bissell, Lewis P., and Gordon L. Chapman. 1952. **Increased yield from thinnings in a natural white pine stand.** Univ. Maine Forestry Dept. Tech. Note 14. 2 pp.

Records over 16 years in a 40-year-old stand where two ¼-acre plots were laid out (one thinned and the other unthinned) show that thinning stimulated growth but that after 10 years or so its effect was gone and another thinning should have been made.

Butler, O. M. 1925. **The pine pruner of Holderness.** Amer. Forests and Forest Life 31: 92-94, illus.

An account of the operations of O. M. Pratt of Holderness, N. H., who managed about 1,000 acres of pine for about 20 years. He pruned white pine to 16 feet when 3 to 4 inchest in diameter, usually after the stand had been thinned. A crosscut saw on a short pole was used to cut both live and dead limbs flush with the trunk.

Clapp, R. T. 1936. **First thinning in white pine plantations.** Jour. Forestry 34: 928-935.

Nearly 30 acres of plantation 26 to 38 years old in the Eli Whitney Forest, near New Haven, Conn. were commercially thinned for the first time. About 100 trees per acre were removed in the dense stands; these cuttings yielded as much as 1,800 board feet of 8- to 12-foot logs per acre. Lighter cuttings were made in the lighter stands, where the average yield was 836 board feet per acre. The author recommended a second thinning in the same stands in 5 to 10 years. Only a small profit resulted from the first thinning.

Cline, A. C., and E. D. Fletcher. 1928. **Pruning for profit as applied to eastern white pine.** Mass. Forestry Assoc. 23 pp.

Pruning small straight trees with small limbs is profitable, but badly weevilled trees or those with large limbs should not be pruned. Dominant trees that are to be retained for the final harvest should be selected for pruning when 3 to 4 inches d.b.h.

Cook, David B. 1951. **Justifications for forest pruning in the northeast.** Jour. Forestry 49: 487-489.

Pruning stimulates quality production (of any forest product) and this is a primary aim of forest management. Pruning increases stumpage values, helps protect the market for forest products, reduces logging and processing costs. It improves fire protection and soil conditions, improves the wildlife habitat, helps prevent infection by white pine blister rust and certain cankers, and provides off-season labor for forest labor forces.

Curtis, James D. 1936. **A method of pruning dead branches.** Forestry Chron. 12: 291-299.

Although no final conclusions can be drawn from the results obtained in this study, it would seem that in so far as the formation of callus is concerned, pruning dead branches close to the trunk so as to cut through and expose green tissue gives promising results after 1 year's growth.

Downs, Albert A. 1944. **Growth of pruned eastern white pine.** Jour. Forestry 42: 598.

The conclusions of Barrett and Downs (1943) were confirmed by data taken on the same study 3 years later. Eight years after treatment there were no statistical differences in height or diameter growth among three degrees of pruning. Pruning of 26 to 35% of the live branch whorls can be safely used with white pine. Total loss of diameter growth as a result of such pruning was about 1/10 inch.

Foster, Clifford H. 1929. **Thinnings in natural stands.** Jour. Forestry 27: 804-806.

Urges that thinning in young natural softwood stands supplant the common practice of clearcutting. By proper thinning, the financial rotation can be extended, which will mean less risk from destructive agencies in young stands, and will increase crop value and attractiveness of the investment. Logging costs will be decreased.

Frothingham, E. H. 1942. **Twenty years' results of plantation thinning at Biltmore, N.C.** Jour. Forestry 40: 444-452.

Concludes that light thinnings from below are porfitable because they salvage material that would die and also increase growth in both volume and quality. Heavy thinnings are to be avoided because they reduce net growth rather than increase it. The white pine plantations studied are now 40-45 years old and have been thinned four times. Based on several very small but uniform plots.

Glattfelter, Calvin F. 1952. **Report on bud-pruning of forest trees.** Pa. Dept. Forests and Waters 4: 52-53, 71, illus.

White and red pine and Japanese larch were bud-pruned for 3 years with little mortality or damage. White pine could be bud-pruned at the rate of 54 to 90 trees per man-hour, but there are indications that pruning of 1-year-old twigs is more efficient. White-pine weevil damage increased in both pruned and unpruned parts of the plantation.

Hawley, Ralph C. 1922. **A progress report of the results secured in treating pure white pine stands on experimental plots at Keene, New Hampshire.** Yale Univ. School Forestry Bul. 7, 32 pp.

Plots for study of repeated thinnings and a check plot were established in 1905 in a 35-year-old white pine stand on sandy site III soil. Three thinnings have been made in the 15-year period reported. The results show a reduction of 70% in tree numbers, concentration of growth on fewer and larger stems, salvage of mortality and increase in volume growth. A study of successful regeneration following two thinnings and harvest cutting by the shelterwood method in a 48- to 61-year-old stand is described.

Hawley, Ralph C. 1936. **Observations on thinning and management of eastern white pine (*Pinus strobus* Linnaeus) in southern New Hampshire.** Yale Univ. School Forestry Bul. 42, 16 pp., illus.

Third report on thinned and check plots established in 1905 near Keene, N. H., and remeasured over a 30-year period. Describes expermental area, treatments, and results. Increased diameter growth of 80 largest trees on thinned plot was compared with 80 largest on check plot. The height growth was not changed by thinning. However, volume growth in board feet did increase. Better financial returns resulted from early thinnings. Suggests plans for silvicultural operations to grow even-aged white pine crops on sandy soils.

Hawley, Ralph C., and Robert T. Clapp. 1935. **Artificial pruning in coniferous plantations.** Yale Univ. School Forestry Bul. 39. 36 pp.

Describes in detail the technique of pruning and presents data on costs and physical results. Recommends pruning 150 to 200 trees per acre in white pine plantations.

Knapp, F. B. 1913. **Silviculture of white pine (*Pinus strobus*).** Mass. Forestry Assoc. Bul. 106, 4 pp.

Mostly a discussion of pruning. Based on experiments of Nathaniel Morton in Plymouth, Mass., by the Eric Forest School and by O. M. Pratt of Holderness, N. H. The "Eric" method is described: prune early and often to develop one clear log with 4-inch knotty core. Gives estimates of tree size at start and end of pruning, growth, and returns.

Lorenz, R. W. 1948. **Thinning returns from an eastern white pine plantation in Ogle County.** Ill. Acad. Sci. Trans. 41: 39-42.

Results of studies made in four ¼-acre sample plots to determine yields and net stumpage from thinnings made at 34 and 39 years of age. The first thinning yielded (per acre) 390 fence posts and 1,600 board feet of lumber with a total stumpage of $77. The second thinning yielded 450 posts and 860 board feet, a total stumpage of $122 per acre.

Meyer, W. H. 1940. **Pruning natural pine stands.** Jour. Forestry 38: 413-414.

In a mixed pine-hardwood stand about 225 white and red pine (half the total number of stems) per acre were pruned to an average length of 14.7 feet. The trees pruned were 3 to 6 inches d.b.h. The most efficient tools were a 7-point, 14-inch saw on a 7-foot pole for the first 12 feet and a 5-point, 18-inch saw on a 14-foot pole for higher pruning.

Mollenhauer, Wm. J. 1938. **Tools and methods in an experimental pruning of white pine.** Jour. Forestry 36: 588-599, 812, illus.

Of 21 tools, the pole ax used as a mace proved most efficient for pruning dead branches from white pine boles up to 7 feet high. The use of edged tools generally resulted in low efficiency and high hazard to worker and to trees. For bole heights above 7 feet, hand saws were easiest and safest to use; standard pull-stroke models were superior to double-edged saws. Pole saws and pole shears were unsatisfactory. Climbing to desired pruning height and working downward was superior to methods requiring ladders.

New York Conservation Department. 1937. **Thinning recommendations based on study of diameter growth in plantations.** N.Y. Conserv. Dept. Notes on Forest Invest. 1, 1p.

Diameter growth in two successive 5-year periods on 5 unthinned and 2 thinned plots representative of 95 plots studied is presented to show that thinning in 10- to 20-year-old plantations will help prevent falling-off of diameter growth.

New York State Conservation Commission. 1939. **29th annual report.** 65 pp. N.Y. Conserv. Dept.

A relatively cheap method of thinning a 4- by 4-foot white pine plantation is the removal of every third row, and this appears to be the best practical way of admitting light, air, and hardwoods into a closed softwood stand with the object of preventing an accumulation of undecomposed needle litter, a condition known to be detrimental to plantation development.

Paul, Benson H. 1933. **Pruning forest trees.** Jour. Forestry 31: 563-566.

A brief review of pruning investigations and of the most important things remaining to be learned. Pruning of eastern white pine may be especially profitable because of the very poor natural pruning in this species. Pruning programs should be flexible and methods should be carefully chosen in the light of labor requirements.

Rich, J. Harry. 1954. **Dividends from pruning forest trees.** Mass. Univ. Ext. Serv. Leaflet 272, 8 pp.

Scattered information on white pine growth rates, healing rate of pruning scars, costs of pruning, and white pine lumber prices is drawn together. These data are used in examples to calculate the increased lumber values resulting from pruning and the relation that the increased lumber value bears to the cost of pruning. Shows how to determine costs and returns.

Sechrist, William C. 1939. **Profitable utilization of white pine thinnings.** Jour. Forestry 37: 232-235.

Trees 4 to 9 inches d.b.h. were cut into billets and run through a shingle mill to produce shingles and boxboards. The equivalent of about 4 standard cords per acre were produced. Detailed cost records are given and the operation was termed profitable. Markets for small material must be developed if thinnings from such plantations are to be utilized profitably.

Smithers, L. A. 1954. **Thinning in red and white pine stands at Petawawa Forest Experiment Station.** Canada Forestry Branch Silvic. Res. Note 105, 52 pp., illus.

Explores relationships between intensity and frequency of thinning, site class, and most stand characteristics in natural and planted white and red pine stands. Thinnings can be economical if they are begun early (about 30 years of age) and are light but frequent. The thinnings should be well distributed and should favor the growth of specified numbers of crop trees (preferably red pine). Site class yield tables are given for fully stocked stands and for stands in which the suggested thinning regimes are carried out.

Stevenson, Donald D. 1946. **Thinnings in the white pine plantations, Biltmore, North Carolina.** Jour. Forestry 44: 763-765, illus.

Describes a commercial pulpwood thinning in a 46-year-old white pine plantation that had been established with 4,000 trees per acre, of which 600 were left. Thinning reduced the number to 200 trees, all vigorous, well-formed, and in the dominant or codominant crown class.

Wahlenberg, W. G. 1953. **A 37-year test of thinning Appalachian white pine.** South. Lumberman 187 (2345): 180-183, illus.

White pine of uncertain seed source was planted in 1899 on an old orchard site that had eroded badly. Six thinnings (begun at 20 years old) were made at about 7-year intervals. Compared to the unthinned portion of the stand, the thinned portion had in 1953 an additional yield (including the thinnings) of 14 cords of wood and 6.4 thousand board-feet of sawlogs. The difference in stumpage value was nearly $200. Crown ratio is the best single criterion of tree development in the ensuing 10 years and is a practical marking guide.

Wave, Herbert E., David F. Wentworth, and G. L. Chapman. 1952. **A pruning time study for spruce and white pine in uneven-aged natural stands.** Maine Univ. Forestry Dept. Tech. Note 15, 2 pp.

In mixed stands of spruce and white pine where intensive management is possible, pruning to a height of 18 feet with hand and pole saws compares favorably in cost with pruning in plantations. It took 2¾ minutes per tree to prune white pines and 3½ minutes walking time between them. Only two to five trees per acre were pruned and they averaged 7 inches in diameter. Pruning spruce took two to three times as long as pruning pine.

Young, Leigh J. 1931. **Results of thinning in white pine.** Mich. Acad. Sci. Arts, and Letters, Paper 15: 337-348.

A 3 x 3 white pine stand was thinned 11, 21, and 26 years after planting by the Danish system to remove all neutral and injurious secondary trees. In a 4½ x 4½ stand, grade C thinnings were made 21 and 26 years after planting. The thinnings have made only very moderate increases in diameter and current volume growth. Computation of "distance factors" for these plots and some at Keene, N. H., show the relative weight of thinning.

Adams, W. R., Jr., and G. L. Chapman. 1942. **Crop tree measurements in thinning experiments.** Jour. Forestry 40: 493-498.

Analysis of growth measurements on 2,200 trees in thinned plots of a 27-year-old white pine plantation showed that the percentage basal-area growth of the total stand was increased by thinning from above and from below. However, among selected dominant crop trees, thinning made little difference.

Barrett, L. I. 1936. **Recent volume tables for some southern Appalachian species.** U.S. Forest Serv. Appalachian Forest Expt. Sta. Tech. Note 19, 49 pp.

Includes volume tables for white pine on site class I, based on data from the Pisgah National Forest. Volumes are expressed in board feet, Scribner Decimal C log rule, for trees 10 to 36 inches d.b.h., one table giving volumes by ½-log height classes from one to four logs, the other giving both gross and net volume for trees of average height by diameter classes.

Bedell, G. H. D. 1948. **Form-class of white pine and jack pine as affected by diameter, height, and age.** Canada Forest Serv. Silvic. Res. Note 89, 11 pp.

Analysis of form-class data is described and discussed and tables of form class are presented. Those for white pine cover a range in age from 25 to 200 years, in height from 20 to 120 feet, and in d.b.h. from 1 to 30 inches. The form class itself ranges from 48 for the youngest and shortest trees to 79 for small old trees.

Bickford, C. Allen. 1951. **Form-class volume tables for estimating board-foot content of northern conifers.** U.S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 38, 38 pp.

The Mesavage-Girard form-class volume tables are not applicable to northern conifers. These new tables for pine, spruce, fir, hemlock, and cedar fill the need for comparable tables for these species. Volumes given in board feet International ¼-inch rule for trees 10 to 30 inches d.b.h., 1 to 5 logs in merchantable height, and with form class from 65 to 86.

Canada Forestry Branch. 1944. **Interpolated volume tables (total volume) for use in compilation of sample plot data.** Canada Forestry Branch Misc. Ser. 3. (n.p.)

For every inch of diameter and for each foot of height, total cubic-foot volumes are given for several species. The white pine tables are for trees up to 20 inches d.b.h., up to 100 feet high, and with form class 65 and 70.

Canada Forestry Branch. 1953. **Provisional form-class volume tables for Ontario log rule.** Canada Forestry Branch. (n.p.)

These tables use the same data and are an extension of the tables described above. Includes board-foot volumes for white pine trees with form classes 65, 70, and 75, diameters from 6 to 20 inches, and total height from 30 to 90 feet.

Cook, H. O. 1908. **Handbook on forest mensuration of the white pine in Massachusetts.** 50 pp. Boston.

Tables of the volume and growth of trees and stands in Massachusetts are given. Yield tables of volume, stumpage, and lumber value for three site qualities. Financial rotations are tabulated, as are yields from thinnings. The measurement of trees, stands, and round- and square-edged lumber are described.

Demeritt, D. B. 1952. **Second-growth white pine volume tables—southwestern Maine.** Maine Univ. Forestry Dept. Tech. Note 18. 5 pp.

The tables give volumes in board feet by the Maine rule, International ¼-inch rule, and Scribner rule, in cubic feet and in peeled cords. Volumes are given from 1-foot stump to a 6-inch top diameter. Volumes for trees 8 to 31 inches d.b.h. and 40 to 110 feet in total height are given.

Gevorkiantz, S. R., and L. P. Olsen. 1951. **Bark percent in Lake States trees.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 362, 1 p.

Gives regional averages for the major species. White pine poletimber has a bark percentage of 14; in second-growth sawtimber it is 16%, and in old-growth sawtimber 18%.

Hampf, Frederick E. 1954. **Relationship of stump diameter to d.b.h. for white pine in the northeast.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Forest Res. Note 38, 4 pp.

Data from wood-utilization studies in 10 states were used to construct a graph for estimating d.b.h. in inches from stump height and diameter.

Hepting, George H., Elmer R. Roth, and Bailey Sleeth. 1949. **Discoloration and decay from increment borings.** Jour. Forestry 47: 366-370.

Increment borings in white pine resulted in pitch-soaked streaks about 3 inches long.

Hicock, H. W., A. D. Rhodes, and A. R. Olson. 1939. **Volume tables for plantation-grown white pine (*Pinus strobus* L.) in Connecticut.** Conn. Agr. Expt. Sta. Bul. 427. 14 pp.

Total volume in cubic feet and merchantable volume in cubic feet, board feet (International ¼-inch rule) are given in tables and alinement charts for trees 2 to 16 inches d.b.h. and 15 to 65 feet in total height, except that board-feet are shown only for trees 6 to 13 inches d.b.h. and 25 to 60 feet in total height.

Hough, A. F. 1932. **Some diameter distributions in forest stands of northwestern Pennsylvania.** Jour. Forestry 30: 933-943.

White pine in northwestern Pennsylvania was found to be even-aged in second-growth stands and essentially even-aged in virgin stands; but stand graphs based on the entire mixture of species are misleading when used to estimate age conditions in such stands. Age conditions on areas cut in the past may be inferred from stand-distribution graphs by species.

Johnson, F. A., and J. R. Crawmer. 1941. **Volume tables for eastern white pine (*Pinus strobus*) in Holmes County, Ohio.** U.S. Forest Serv. Central States Forest Expt. Sta. Tech. Note 35, 1p.

Volume of the merchantable stem to a variable top diameter is given in board feet (International ¼-inch rule) for trees 7 to 28 inches in diameter and for one to seven 12-foot log lengths. Based on measurements of 96 trees.

Kittredge, J. 1944. **Estimation of the amount of foliage of trees and stands.** Jour. Forestry 42: 905-912, illus.

In a discussion of foliage estimation, white pine data published by Adams (1928), Burger (1929), and Burns and Irwin (1942) are among those used to show the relationship between weight of foliage and volume growth of wood. The same data are used to show a simpler method of estimating foliage weight from tree diameter, where log W = b log D-a. The regressions are all significant.

Lake States Forest Experiment Station. 1936. **Bark thickness of sawtimber trees in Michigan.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 108, 1 p.

The double-bark thickness of white pine in percentage of total diameter is shown to be 10.5% at d.b.h. and 7.5% at 18.3 feet above the ground.

Lyon, Charles J. 1953. **Vertical uniformity in three New England conifers.** Tree-Ring Bul. 20(2): 10-16, illus.

Cross-sections were cut at various heights in a red spruce, a hemlock, and two white pines, all grown in northern New England. One pine was sectioned at 5-foot intervals and the other at 8-foot. The graphs of the ring widths indicate a high degree of uniformity in the sequence of growth rings at different levels in the trees, except those levles well into the crown. Standard correlation coefficients were computed for each species for the period since 1850, using 25-year periods to offset growth trends with changing age. The coefficients for white pine are all positive and highly significant. White pine is consistently the most uniform for relative ring width at different trunk levels and in different 25-year periods.

MacDonald, James. 1932-33. **The form of the stem in coniferous trees.** Forestry 6: 53-62, 143-153; 7: 32-42, illus.

Percentile tapers and comparisons of the percentile measurements with those of the Hojer-Jonson, Hojer, and Behre theoretical stem-form curves are given by form classes for many species, including white pine (19 trees measured). The measurements from these few trees did not conform very well to the theoretical curves, but they are close to those given by Gevorkiantz and Hosley (1929). When root swell is eliminated, all the species are essentially alike inside bark.

Meyer, H. A. 1946. **Bark volume determination in trees.** Jour. Forestry 44: 1067-1070.

The bark volume of a tree may be obtained by multiplying the volume of the tree including bark by the factor $(1 - k^2)$, where k is a constant representing the regression coefficient of d (diameter inside bark) on D (diameter outside bark). Values of k and cubic-foot bark volume in percentage of total volume $(1 - k^2)$ are given for white pine and other species.

Meyer, Walter H. 1930. **Diameter distribution series in even-aged forest stands.** Yale Univ. School Forestry Bul. 28. 105 pp.

The fit of Charlier's Type A and Type B distribution curves to the diameter distributions of various conifer stands was found to be generally good. Data from a few white pine sample plots show that the diameter distributions of managed natural stands tend to be negatively asymetrical; that is, they have relatively more small trees than large ones. The curves for plantations are positively asymmetrical. Distribution series cannot be applied indiscriminately to natural stands and planted stands. The computations to fit these distribution series are explained.

Morey, H. F. 1936. **Age-size relationships of Heart's Content, a virgin forest in northwestern Pennsylvania.** Ecology 17: 251-257.

The relationship of d.b.h. with age and with total height was studied in 800 trees of the principal species at Heart's Content. White pine was the species with the largest d.b.h. and total height, but the oldest tree was a hemlock.

Mulloy, G. A. 1944. **Stand density vs. stand bole area and stand intensity indices in even-aged stands.** Forestry Chron. 20: 167-170.

Data from a large number of red and white pine plots at the Petawawa Forest Experiment Station were used to compare these indices. It appears that the stand bole-area index has the advantage of easy computation, being simply the product of average diameter, average height, and number of trees per acre. However, it has not yet been tested to the extent that stand-density index has.

Olson, A. R., Gordon L. Chapman, and H. W. Hicock. 1948. **Connecticut volume tables for plantation grown white pine.** Conn. Agr. Expt. Sta. Bul. 514. 23 pp.

Tables and alinement charts give volumes in cubic feet of solid stem wood, excluding stump; in cubic feet of stem wood and bark between stump and 2.0-inch d.o.b. and also between stump and 5-inch d.o.b.; and in board feet (International ¼-inch rule) for the stem between stump and 5-inch d.o.b. Tables cover trees ranging from 2 to 18 inches d.b.h. and 15 to 90 feet in total height. Details of volume-table construction are also given.

Paton, R. R., and L. J. Leffelman. 1928. **Preliminary report on partial measurements of forest plantations.** Jour. Agr. Res. 36: 91-96, illus.

Plantations of white pine and other species were used to study the errors of estimate resulting from measurement of a sample of the trees to determine volume. It appears that fewer measurements of height than of diameter may be needed for the same level of accuracy.

Roberts, Cecil M., and Harold E. Young. 1953. **Aids for computing tree volume in Maine.** Maine Univ. Forestry Dept. Tech. Note 19, 5 pp.

For white pine and several other species, average form class, double-bark thickness, and merchantable length to a 4-inch top are given by diameter class. The d.b.h. corresponding to stump diameters inside and outside bark are also given.

Schantz-Hansen, T. 1922. **Frustum form factor volume tables for white, Norway, and jack pines in Minnesota.** Jour. Forestry 20: 714-728.

The tables for white pine cover trees 8 to 40 inches d.b.h. and 2 to 7 logs high.

Spaulding, Perley. 1937. **Estimating the length of time that trees have been dead in northern New England.** Jour. Forestry 35: 393-395, illus.

In white pine some of the needles persists through the 2nd year after death and a few small shelf fungi may fruit. In the 3rd year the bark loosens and *Fomes pinicola* begins to fruit; sapwood is rotten but not punky. In the 4th and 5th years the sapwood becomes punky and smaller fungi are plentiful. During the 6th to 10th years the small annual fungi decrease in number, sapwood is well rotted, and branches begin to fall.

Turberville, H. W., and A. F. Hough. 1939. **Errors in age counts of suppressed trees.** Jour. Forestry 37: 417-418.

A study in the Allegheny National Forest showed that some annual rings were missing in suppressed or very slow-grown trees, particulary hemlocks and hardwoods. One suppressed 122-year-old white pine formed no visible rings at ground level in 28 recent years.

Wilson, F. G. 1946. **Numerical expression of stocking in terms of height.** Jour. Forestry 44: 758-761, illus.

On the basis of some thinning experiments with associated species it is suggested that pure white pine stands might be kept at a spacing equal to 1/5th to 1/6th of total height for best growth.

STAND GROWTH & DEVELOPMENT SITE APPRAISAL

Allison, J. H. 1943. **Forty years' growth of planted pines in north central Minnesota.** Jour. Forestry 41: 449-450.

Records on these previously reported plantations (Allison, 1923) show that weevilling seriously reduced height growth of the white pine up to 25 years of age, but there has been little weevilling since. Red and jack pine are considerably taller than the white pine where they were seeded into the pure white pine plantation and where the three species were planted in alternate rows. In the latter case the white pine is badly suppressed.

Ardenne, M. 1950. **Growth of second growth red and white pine in southeastern Ontario.** Ontario Dept. Lands and Forest Res. Rpt. 18, 13 pp., illus.

Growth in young white and red pine stands was studied by increment borings and plot measurements in fairly well stocked stands in and near Algonquin Park. Site classes were set up on the basis of height growth of dominant and co-dominant trees. The results, shown in graphs and tables, are used as a basis for estimating future yields.

Baldwin, Henry I. 1949. **Some older white pine plantations in New Hampshire.** Jour. Forestry 47: 347-399.

Reports measurements on three small plantations 40 to 60 years of age in 1948 The youngest was spaced 8 x 8 feet while the other two were spaced about 15 x 15 feet. All are now nearly fully stocked and have current annual increment of more than 1,000 board feet. The average d.b.h. of the wider-spaced plantations is 16 inches while the closer-spaced one has an average d.b.h. of only 9 inches.

Barrett, L. I. 1933. **Growth rate of northern white pine in the southern Appalachians.** Jour. Forestry 31: 570-572.

In northern Georgia, white pine reproduction was beginning to occupy an important place in the overstory over extensive areas. Growth studies of overstory trees showed that white pine grows significantly faster in diameter than do its associates, yellow-poplar, yellow pines, and the oaks. There was close correlation between age and diameter for white pine and some other species. The trees studied ranged in age from 20 to 110 years.

Belyea, Harold Cahill. 1924. **A study of comparative height growth of six planted species.** Jour. Forestry 22: 389-391.

In Otsego County, N. Y., the plantations were spaced 6 x 6 feet on sandy loam with a water table close to the surface. Red pine showed best vigor and growth after 15 years. White pine grew higher than red pine until the 13th year; the greatest difference came in the 8th year. Thereafter, heavy weevilling of the white pine constantly reduced its height in relation to red pine.

Brinkman, K. A. 1951. **Growth of a white pine plantation in Iowa.** Jour. Forestry 49: 445.

About 700 trees per acre were set out on a wind-blown sandy ridge 51 years ago and have been unmanaged since then. The plantation has made an average annual net growth of 137 cubic feet or 656 board feet per acre and now contains 425 trees per acre with an average diameter of 10.9 inches. Growth in basal area rose to a maximum (8.0 square feet per acre annually) in the third decade and then steadily decreased.

Brown, R. M., and S. R. Gevorkiantz. 1934. **Volume, yield, and stand tables for tree species in the Lake States.** Univ. Minn. Tech. Bul. 39, 208 pp.

For eastern white pine there are nine different volume tables, three Girard form-class-taper tables, a site-index graph, and yield tables for five site classes which show, for various ages, the average height of dominant trees, and for all trees 1 inch and more in d.b.h., the average height, average diameter, number of trees, basal area, and cubic-foot yield. Gives yield in board feet International ¼-inch rule for trees 7 inches d.b.h. and over and by the Scribner Decimal C rule for trees 8 inches d.b.h. and over.

Cutten, E. Y. 1950. **The development of a stand of *Pinus strobus* L. in Waiotapu State Forest.** New Zeal. State Forest Serv. Forest Res. Notes 1: 19-27, illus.

The white pine was planted in 1907 at 8 x 8 foot spacing, and interplanted with Austrian pine spaced 4 x 4 feet. Sample plots were established in 1925 and measured and thinned in 1925, 1928, 1938 (not thinned), and 1948. The Austrian pine had disappeared from the thinned plots by 1938 and from the check plot before 1948. In 1948 the average d.b.h. in thinned plots was 12.5 to 13.3 inches, and in the unthinned plot 10.8 inches. The average height of dominant trees was approximately 90 feet.

Deen, J. L. 1933. **A survival table of even-aged stands of northern white pine.** Jour. Forestry 31: 42-44.

Based on measurements of permanent sample plots in Massachusetts and southern New Hampshire, a table is presented that gives the percentage of trees (in each diameter class from 1 to 14 inches) that may be expected to survive the ensuing 10-year period. The table may be used to refine growth estimates and to reconstruct stocking in the past.

Donahue, Roy L. 1936. **The relation of soil character as expressed by certain soil types to the choice of land for forestry in the cut-over pine lands of northern Michigan.** Amer. Soil Survey Assoc. Bul. 17: 79-80.

Eight soil types were grouped into three classes of site for pine based on their general profile characteristics. A sandy loam texture is said to contribute toward good sites for pine; a yellow B layer, fine sand, or infrequent sandy clay lenses contribute toward fair sites; and a hardpan or coarse dry soil make for a poor site.

Dwight, T. W. 1926. **The use of growth charts in place of yield tables.** Jour. Forestry 24: 358-377.

Data from white pine stands in Ontario are used to illustrate the method of estimating growth on the basis of the present diameter of the trees. The advantages of this method over yield tables are discussed.

Einspahr, Dean, and A. L. McComb. 1951. **Site index of oaks in relation to soil and topography in northeastern Iowa.** Jour. Forestry 49: 719-723.

Site index of oaks was studied in relation to soil series, soil-profile characteristics, and topography on 108 site-index plots. The prediction of site index of oak for various soil series and land types seems to be practical. Where eastern white pine was growing in mixture with oaks, pine had higher site indices; the site-index differences were greatest on the poorest oak sites. On the same site, stands with white pine carried much greater volumes at the same ages.

Fenska, R. R. 1922. **Yield table for white pine.** Jour. Forestry 20: 593-597.

Yield table based on measurements of all known white pine plantations over 25 years old in Rhode Island, Massachusetts, and New Hampshire (range in age is from 27 to 63 years). The mean annual growth per acre increased from 400 board feet with a 25 to 35 year rotation to 600 board feet with a 55 to 65-year rotation. The maximum financial returns were with a 50-year rotation.

Gaiser, R. N., and R. W. Merz. 1953. **Growth of planted red and white pine in Ohio and Indiana.** U.S. Forest Serv. Central States Forest Expt. Sta. Tech. Paper 138, 14 pp.

In studies in old fields in the unglaciated regions of Ohio and central Indiana, the average height of dominants and codominants 25 years after planting was 51 feet for white pine and 38 feet for red pine, with d.b.h. of 8 inches and 6 inches, respectively. Red pine grew more rapidly in height and diameter in mixture with other species; white pine grew more slowly in height at first but after the 20th year trees in mixed plantations were taller than those in pure plantations.

Gibbs, J. A. 1953. **Planted white pine makes good growth at Mohican.** Ohio Agr. Expt. Sta. Forest Mimeo. 7, 1 p., illus.

Measurements made in a 20-year-old plantation of white pine on a typical abandoned hillside field showed average d.b.h. was 5.8 inches, average height 36 feet.

Hawley, Ralph C. 1918. **Does eastern white pine occur on sites IV and V?** Jour. Forestry 16: 341-343.

White pine does not normally grow or reproduce itself on sites IV and V as Recknagel (1917) contends. Hawley recognizes such sites as sterile sand plains or ridge tops above 1,500 feet elevation. The site-index values of Frothingham (1914) are used for discussion.

Hazard, Helen E. 1937. **Plant indicators of pure white pine sites in southern New Hampshire.** Jour. Forestry 35: 477-486.

Five indicator types and five subtypes are described and their relationships to the soil and the forest are discussed. In southern New Hampshire, the Cladonia, Vaccinum, and Maianthemum-Vaccinium types should reproduce white pine if there is a good seed source. The Maianthemum and the Rich Herbacious types are too rich to reproduce white pine in competition with hardwoods.

Heiberg, Svend O. 1933. **Factors influencing choice of species in artificial reforestation.** Jour Forestry 31: 311-317.

Particularly in New York and New England, the factors to be considered are planting-site quality and accessibility, site and silvicultural requirements, costs of establishment and protection, economic value, and available seed sources of the species that might be planted. As a valuable species but one expensive to plant and protect, white pine should be used only on the best and most accessible planting sites, where it can be managed intensively.

Henderson, W. M., E. L. Brown, and M. McKay. 1945. **A determination of yield on the University of New Brunswick woodlot.** Forestry Chron. 21: 196-204.

The forest is composed of mixed stands containing spruce, fir, hemlock, and white pine. About one-third of the board-foot volume is white pine, ranging in diameter from 6 to 20 inches. Regulation of the cut by a stand-projection method is explained and illustrated.

Herbert, P. A. 1924. **Sand ridge produces valuable timber.** Mich. Agr. Expt. Sta. Quart. Bul. 6: 177-180.

Ten years after planting on a ridge of very light wind-blown sand, ponderosa pine and eastern white pine transplants had grown more than 1 foot in height per year. Although the white pine grew somewhat faster in height than the ponderosa, the latter attained greater d.b.h. and volume and had somewhat better survival. Norway spruce and Douglas-fir have not been successful.

Hills, G. A. 1952. **The classification and evaluation of site for forestry.** Ontario Dept. Lands and Forest Res. Rpt. 24, 41 pp., illus.

Describes a site classification based on measurement and integration of physiographic, biological, and cultural features. Because of their stability, rather than their importance, physiographic features were chosen as the frame of reference for total site. The major physiographic features are eco-climate, soil-moisture regime, and nutrient regime. The application of the classification on a regional basis in Ontario is given as an example. White pine is shown to be an important component of the characteristic forests.

Husch, B. 1954. **Preliminary site index table for white pine in southeastern New Hampshire.** N.H. Univ. Dept. Forestry, Forestry Mimeo. 1, 2 pp.

Based on 30 sample plots, a site-index table and graph with reference age of 50 years is given, covering site indices from 45 to 75 and stand ages from 20 to 80 years.

Kimberly, J. T. 1933. **Growth rate of white pine in the southern Appalachians and New England.** Jour. Forestry 31: 946-947, illus.

For the two localities, the curves of diameter and of height over age were parallel and nearly parallel, respectively. There was a significant difference between them of about 3.4 inches in diameter and about 23 feet in height. The trees of the southern Appalachians were, of course, the larger. Only dominant and codominant second-growth trees were measured. Age was determined by borings at 4.5 feet above the ground.

Li, T. T. 1923. **Do thinnings actually increase growth per acre as compared to unthinned stands?** Jour. Forestry 21: 125-128.

Data from Hawley (1922) are retabulated to show loss through mortality. It is concluded that thinnings resulted in net periodic growth approximately 123 to 134% greater than the growth on the check plot. Of this increased net growth, 43 to 57% is attributable to utilization of material lost by death in the unthinned stand, and 42 to 57% to accelerated production in the thinned stand.

Lorenz, R. W., and J. Nelson Spaeth. 1947. **The growth of conifers on prairie soil.** Jour. Forestry 45: 253-256, illus.

Over a period of 70 years, the growth of white pine and three other conifers planted on prairie soil in Illinois has not lived up to expectations based on early development. At 20 years the site index of the white pine was 90; at 40 years it was 54; and at 70 years it was only 44 (based on Frothingham 1914). At 70 years the white pine plantations had an average diameter of 11 inches, a basal area of 137 square feet, and a volume of 22,800 board feet.

McConkey, Thomas W. 1953. **Growth behavior of white pine in an uncut stand in southwestern Maine.** U.S. Forest Serv. Northeast. Forest Expt. Sta., Res. Note 25, 3 pp.

Measurements of growth in a mixed stand of white pine, hemlock, and scattered hardwoods over a 15-year period showed that some trees contribute more than three times as much to the stand growth as other trees of the same size and species. The years a tree needs to grow 1 inch in diameter is a good guide to its thrift and condition; pine and hemlock should grow 1 inch in diameter in less than 7 years.

Minckler, Leon S. 1946. **Old field reforestation in the Great Appalachian Valley as related to some ecological factors.** Ecol. Monog. 16: 88-108, illus.

In general, shortleaf pine, eastern white pine, yellow-poplar, and white ash were the most successful species to plant. Growth and survival of all species varied with soil type and aspect. Species with a good growth on a given site tended to have good survival also. A planting chart summarizes the site characteristics most suitable for the various species.

Mlodziansky, A. K. 1898. **Acre-yield of white pine.** Amer. Forestry Assoc. The Forester 4: 143-144, 163-165.

The volume of uncut white pine timber on 4 lots in Pennsylvania and 12 lots in the Lake States varied with stand condition and site from 12,000 to 67,000 board feet per acre.

Mulloy, G. A. 1943. **A practical measure of stock density in white and red pine stands.** Forestry Chron. 19: 108-118.

Determination of stand density by comparison of total basal area with that from normal yield tables is often impracticable. An index of density is required that is independent of both age and site. The index developed by Reineke (1933) was checked against records for 20 years of sample-plot data for thinned and unthinned red and white pine stands. In practice it is necessary merely to estimate the average diameter of the stand then the spacing for optimum development can be determined.

Mulloy, G. A. 1944. **Empirical stand density yield tables.** Canada Forest Serv. Silvic Res. Note 73, 22 pp.

The construction and usefulness of such yield tables is discussed and tables are given for the white and red pine, jack pine, and balsam-spruce cover types in the Timagami district. They show the method of construction and are only tentative. Volumes are expressed in total cubic feet.

Mulloy, G. A. 1947. **Empirical stand density yield.** Canada Forest Serv. Silvic Res. Note 82, 41 pp., illus.

An extension of work already reported (Mulloy, 1944) on the white birch-aspen-balsam-spruce type of New Brunswick. Evidence on the trends of stand-density index in thinned white and red pine stands at Petawawa is also presented. Development in density of stands after thinning will follow the same trends with age as would be the case had the stand reached this density naturally.

Pinchot, Gifford, and H. S. Graves. 1896. **The white pine; a study, with tables of volume and yield.** 102 pp., illus. New York.

An early work analyzing the growth and yield of white pine with remarks on its situation and occurrence in the forest and its relation to associate species. The observations and measurements were made in first-growth and second-growth pine stands in central Pennsylvania. Valuation surveys of a few groups in New York were used in yield-table construction. Volume tables, curves of yield, and other supplementary information are also included.

Recknagel, A. B. 1917. **More about sites.** Jour. Forestry 15: 929-930.

Measurements of the development of white pine stands on the Luther Preserve, Saratoga County, New York, are given to show that sites that would be classified as IV or V in Europe do occur in eastern United States.

Roe, Eugene I. 1935. **Forest soils—the basis of forest management.** U.S. Forest Serv. Lake States Forest Expt. Sta., 9 pp., illus.

In an extensive study based on some 4,700 miles of road traverse and 15,000 plots, generally good relationships of surface soil texture, character of subsoil, and depth of water table (as determined from mapped soil types) with the occurrence of forest types and site quality for some type species were found. Because few red and white pine stands were encounterd, they were grouped with jack pine in the forest type-analysis. White pine was one of five species for which site-quality relationships were analyzed.

Roe, Eugene I. 1953. **Comparative height growth of native conifers in northeastern Minnesota.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Notes 389, 1 p.

A rocky upland site was planted with 2-0 stock. Jack pine and tamarack averaged 15 feet in height after 10 years. Red and white pine had an average height of nearly 9 feet in the same period (maximum height was 14 feet for white pine and 12 feet for red pine). The spruces made the poorest growth, averaging less than 8 feet for black spruce and 6 feet for white spruce.

Skog, R. E. 1951. **Growth of mixed red and white pine plantations in the Upper Peninsula.** Mich. Agr. Expt. Sta. Quart. Bul. 34: 30-34.

Data collected in a 25-year-old alternate-row plantation of red and white pine show that red pine is growing well. White pine, partly as a result of weevil attacks, is becoming suppressed and is slowing down in diameter growth.

Stanley, Oran B. 1938. **Indicator significance of lesser vegetation in the Yale Forest near Keene, N.H.** Ecology 19: 188-207.

The relation of vegetation types to texture and moisture and nutrient content of the soil, and to light intensity, density, and growth rate in white pine stands was studied. As judged by the density and growth rate of the white pine stands, the *Maianthemum* and *Cornus-Lycopodium* vegetation types and the *Aspidium-Dicksonia* and *Mitchella-Pteris* sub-types are characteristic of the more productive soils of the region. The *Cladonia-Andropogon* and *Vaccinium-Gaultheria* types were grouped as characteristic of the less productive soils.

Stewart, G. 1935. **Criteria of fertility levels as a guide to planting old fields.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 17, 2 pp.

Sites of unusual fertility have a cover of Kentucky blue grass, bent grasses, and clover; hardwoods may be planted on these sites. Sites of average fertility will display mostly bent grasses with some Kentucky blue grass, Canada blue grass, red top, and sweet vernal; these sites are well suited to white pine and the spruce. On sites of low fertility, grasses will comprise less than half the cover and poverty grass will be the most important element. These sites will successfully support conifers adapted to the local climate.

Stoeckeler, Joseph H., and Gustaf A. Limstrom. 1942. **Ecological factors influencing reforestation in northern Wisconsin.** Ecol. Monog. 12: 191-212, illus.

Availability of soil moisture throughout the first growing season was the most important single factor affecting planting success with red and jack pine. In direct seeding of these species and white pine, soil moisture was still a critical factor but surface soil temperature, light, and biotic factors were probably of equal importance.

Stoehr, H. A. 1951. **Growth and yield from a 50-year-old white pine plantation.** Mich. Agr. Expt. Sta. Quart. Bul. 33: 426-436.

The Beal Pinetum, a 3-acre plantation, was established in 1896. In 1950 the stand averaged 13.2 inches d.b.h., 78 feet high, and contained 16,500 board feet per acre.

Wappes, L. 1934. **Wuchsleistungen der Weymouthskiefer.** Deut. Forstwirt 16 (74): 779-784.
Compares growth and yield of *Pinus strobus* in various regions of Germany with that of native Norway spruce, Scotch pine, and European beech. In 1896 and 1897, the author had previously published material on the silvics and yield of white pine. Results in 1934 show relatively good growth despite damage by blister rust. However, before white pine can be widely recommended, more information must be secured on the ultimate effects of blister rust.

Wilde, S. A. 1935. **The significance of soil texture in forestry and its determination by a rapid field method.** Jour. Forestry 33: 503-508.
The silt plus clay content of the soil is a measure of soil fertility or nutrient availability. It also affects moisture relationships. An acceptable planting site for white pine should have a silt plus clay content of 15 to 35% in the upper soil horizon. All soil horizons should be sampled for texture since the relative position of the fertile layers is also important, especially in estimating site for planting. A simple hydrometer method of texture determination is described.

Wilde, S. A., and W. E. Patzer. 1940. **The role of soil organic matter in reforestation.** Amer. Soc. Agron. Jour. 32: 551-562.
A study was made in central and northern Wisconsin of the effect of the organic-matter content of podzolized sandy soils upon the growth of young plantations of jack, red, and white pine, and white spruce. In these soils the organic-matter content showed a close relationship to the total nitrogen and the available phosphorus and potassium contents. Results suggest that the absolute minimum requirement of soil organic matter is 2.5% for white pine.

Wilde, S. A., F. G. Wilson, and D. P. White. 1949. **Soils of Wisconsin in relation to silviculture.** Wis. Conserv. Dept. Pub. 525-549, 171 pp., illus.
The forest soils of Wisconsin are discussed in three main groups: immature soils, soils of the podzol region, and soils of the prairie-forest region. Each of the major forest-soil types and the climax forest it supported are described. White pine was a component of the virgin forest on many of the soil types, most of them in the podzol region.

Worley, David, and H. Arthur Meyer. 1951. **The structure of an uneven-aged white pine-hardwood forest in Luzerne County, Pennsylvania.** Pa. State Forestry School Res. Paper 15, 4 pp.
Cruises of two essentially virgin stands disclosed that the diameter distributions are well balanced and can be expressed by an exponential distribution function. A volume of 5,000 cubic feet per acre could be maintained indefinitely. White pine, occurring primarily in the large and middle diameter classes, is gradually disappearing from the stands in favor of hemlock, maple, and beech.

Young, Harold E. 1954. **Forest soils-site index studies in Maine.** Soil Sci. Soc. Proc. 18 (1): 85-87.
The field, laboratory, and analysis technique employed by Coile in the South have been used in a study of 16 plots in 16 different white pine stands in the vicinity of Orono, Me. A regression equation that related site index with depth of the A horizon and the percent of stones in the Z horizon was developed. As both of these factors increase, the site index decreases. Successful field checks were made around Orono and in the southern part of the State. A regression equation for spruce-fir stands was also developed.

WEATHER

Basham, J. T. 1953. **Extensive tree mortality caused by hail in Quetico Provincial Park.** Canada Dept. Agr. Div. Forest Biol. Bimo. Prog. Rpt. 9 (5): 2.

Examination of a large area in which almost all trees were dead showed that they had been killed by a severe hail storm, probably during the 1951 growing season. All species were affected, but white pine was among the most susceptible.

Belyea, H. C., and H. J. MacAloney. 1926. **Weather injury to terminal buds of Scotch pine and other conifers.** Jour. Forestry 24: 685-690.

Coniferous plantations in Oswego County, N. Y., suffered leader damage by frost in 1917, 1921, and 1922. This was attributed by Belyea (1923) to white-pine weevil. The authors suggest that Scotch pine protects subdominant white pine by forcing higher and wider flight of adult beetles. Describes frost injury and ways to distinguish it from weevil injury.

Canada Department of Agriculture. 1954. **Condition of white pine *(Pinus strobus)* in the Sudbury District.** Canada Forest Insect Dis. Survey Rpt. 1953: 81-82.

In areas near the source of SO^2 in the atmosphere there was an increase in the number of trees showing foliage injuries, which corresponded with the increases in age of the foliage. There was a steady decline in increment on plots near the source of fumes and many young trees showed signs of sunscald.

Craighead, F. C. 1941. **An effect of drought on white pine.** Jour. Forestry 39: 618-619.

Near Carlisle, Pa., the drought of 1935-36 severely reduced current growth in a small white pine plantation. Needles were an inch or less in length and terminal growth was only 3 to 5 inches compared to about 20 inches on the same trees in previous years. All the trees recovered and made normal growth in succeeding years. A similar drought in 1939 had no affect on growth.

Curry, John R., and Thomas W. Church, Jr. 1952. **Observations on winter drying of conifers in the Adirondacks.** Jour. Forestry 50: 114-116.

In the winter of 1947-48 winter injury was severe throughout New York. In the Adirondacks the injury first appeared as a browning of needles that was most severe on the southern and western portions of exposed trees and on limbs just above snow line. Red spruce was most seriously affected, followed in descending order by hemlock, white pine, and balsam fir. In typical conifer stands nearly 50% of the trees had some winter injury.

Curtis, James D. 1936. **Snow damage in plantations.** Jour. Forestry 34: 613-619.

A white pine is occasionally subject to snow breakage if it is closely spaced and has a one-sided crown. The study embraced 22 species.

Curtis, James D. 1943. **Some observations on wind damage.** Jour. Forestry 41: 877-882.

Damage by the 1938 hurricane to forest stands in central New England was studied to find clues to better protection of stands from wind. Up to 25 years of age white pine appears to be more resistant to wind than either Scotch or Norway pine. Trees with a long crown, open crown, or small high crown and thin, flexible trunk are the most resistant to wind. Older, dense, even-staged stands are most susceptible to winds because they have high form points and poorly developed root systems.

Huberman, M. A. 1943. **Sunscald of eastern white pine, *Pinus strobus* L.** Ecology 24: 456-471, illus.

Sunscald seriously injures the cambium on the southwest side of exposed tree trunks, thus lowering tree value and reducing tree vigor. Sunscald was found on white pine averaging 4 to 10 inches in diameter, 31 to 51 years old, of intermediate crown class, and with back thickness of 3.7 to 7.5 mm. It appears to be a winter injury, and rapid freezing the probable cause.

Krečmer, V. 1952. **Vliv sucha roku 1947 zejména na výškový přírůst lesních dřevin. (Effect of the 1947 drought, in particular on the height increment of forest trees.)** Sborn. čsl. Akad. zeměd. 25 (3): 243-260.

Presents the results of an investigation into the factors causing the characteristic dryness of the Brnik Forest District near Kostelec (Bohemia), and the damage brought about by the 1947 drought. The drought had an adverse effect on the 1947 height growth, particularly for white pine, which can be explained by the intensity of the drought and by its having started early in the spring after a not very favorable winter.

Lake States Forest Experiment Station. 1939. **Comparative resistance of native Wisconsin trees to snow breakage.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 152, 1 p.

A wet, heavy snow storm in the latter part of October 1938 caused considerable breakage, bending, and uprooting in the forests of northern Wisconsin. Very little white pine was damaged. In the 4-inch and smaller d.b.h. class, 2% of the white pines were broken or uprooted and in the 5- to 9-inch d.b.h. class 3% of the pines were broken. Larger pines were not damaged at all except for some breakage of smaller limbs.

Lake States Forest Experiment Station. 1936. **Winter injury to plantations.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 117, 1 p.

White pine and red oak planting stock of unknown origin had good survival and growth at Dukes, Mich., for the first few years but when they became more than 4 feet high (the average snow depth) they were repeatedly killed back by the extreme winter conditions. Many of the white pines eventually died. It is a mistake to plant stock of unknown origin.

Lake States Forest Experiment Station. 1935. **What trees withstand drought best?** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 97, 1 p.

Plantations of Norway, white, jack, and Scotch pine planted in 1932 on the Huron National Forest were severely damaged by the drought of 1933. In the southern part the drought was extremely severe and in the northern part the drought was less severe but the rainfall was below normal. White pine was most susceptible to both drought intensities.

Lake States Forest Experiment Station. 1935. **What rainfall factor causes drought damage?** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 98, 1 p.

Studies of white and other pines on the Huron National Forest indicate that the distribution of rainfall over a period of several months is important to survival. In 1933 there was an unusually wet spring followed by a warm, early summer. The trees produced long succulent shoots and as a result first-year planting survival was very low. The spring of 1934 was drier than normal, and consequently the trees produced short shoots only and first-year survivals were uniformly fair to excellent.

Mergen, François, and Herbert I. Winer. 1952. **Compression failures in the boles of living conifers.** Jour. Forestry 50: 677-679, illus.

Compression failures were reported in white pine in New Hampshire. Injured trees are susceptible to breakage during storms. Tall and slightly tapered young trees in dense poletimber stands are especially subject to this kind of injury after thinning.

Moss, A. E. 1940. **Effect on trees of wind-driven salt water.** Jour. Forestry 38: 421-425.

White pine appeared to be the species most sensitive to injury from wind-blown salt water even if diluted by heavy precipitation. The foliage turned orange-red. The effects may be felt at a distance of 45 miles from the ocean when wind velocities are over 100 miles per hour. The injury occurs only where the specimen is exposed to direct force of the wind.

Pirone, P. P. 1941. **Freak weather damages trees and shrubs.** N.J. Agr. 23 (3): 1.

In spring 1941 wilting and browning of many evergreen ornamentals, including yews, junipers, and white pine, was widespread in the Atlantic Seaboard region of the United States. The damage, which was most severe in recently transplanted trees and those with poor root systems or on unfavorable sites, was attributed to strong polar winds in March which caused leaves to transpire more water than could be replaced from the frozen soil, followed by exceptionally mild weather and a heat wave in early April.

Schantz-Hansen, T., and Philip N. Joranson. 1939. **Some effects of the 1936 drought on the forest at the Cloquet Forest Experiment Station.** Jour. Forestry 37: 635-639.

The differences between the average surface areas of the needles produced by jack, red, and northern white pine in the drought year 1936 and those produced during the more normal growing season of 1935 were, without exception, found to be highly significant. In a stand of red and northern white pine ranging from 30 to 40 feet in height and located on a thin soil underlain by rock, approximately half of the total number of trees (and nearly all the red pines) were killed.

Shirley, Hardy L. 1934. **Observations on drought injury in Minnesota forests.** Ecology 15:42-48.

A survey of reproduction losses due to drought was made in swamp and pine forests. In pine forests the losses decreased in severity with increasing height and density of reproduction, and with increasing density of brush and upper canopy. The unfavorable effect of root competition of older trees was more than offset by the beneficial effects of this shade. Losses of white pine were slight where the trees were 1.5 feet or more high and the stand was at least 45% stocked.

Stoeckeler, J. H., and Paul O. Rudolf. 1949. **Winter injury and recovery of conifers in the upper Midwest.** U.S. Forest Serv. Lake States Forest Expt. Sta., Sta. Paper 18, 20 pp.

A sudden, sharp frost following an abnormally warm period in February 1948 caused severe frost damage to trees. White pine showed extensive browning (up to 100% of needles killed) and some sunscald, but made good recovery by September. There was no white pine mortality and little deformity except in trees with very heavy defoliation.

Stone, E. L., Jr. 1952. **An unusual type of frost injury in pine.** Jour. Forestry 50: 560.

A mid-June frost was probably responsible for the distortion of 1950 terminal shoots in New York plantations of white, red, jack, and Scotch pine. The damage varied from a simple offset to a pronounced S-shaped crook in more than one place. Types of recovery from the injury are described.

Wallace, R. H., and A. E. Moss. 1939. **Salt spray damage from recent New England hurricane.** Natl. Shade Tree Conf. Proc. 15: 112-119.

White pine was one of the species most seriously injured by salt spray. Foliage of injured trees took on a bright orange-yellow hue, and the tips of injured needles were invariably killed. Conifers have not recovered well from the injury.

FIRE : ANIMALS

Aldous, Shaler E. 1939. **Pine in the diet of white-tailed deer.** Jour. Forestry 37: 265-267.

Deer browsing of pine was reported heavy in the Superior National Forest. Jack pine seemed to be the preferred species but white pine was eaten in large quantities, especially during the winter when jack pine was less available.

Banks, Wayne G., and James C. Rettie. 1949. **Restocking conditions on the burned-over forest lands of southwestern Maine, June 1949.** U.S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 30, 9 pp., illus.

Forest fires in 1947 burned over some 130,000 acres in the white pine region of Maine. Surveys made in 1949 showed 73,300 acres (56%) adequately stocked with pole timber or sawtimber or desirable seedlings, or with seed sources for natural regeneration; while 56,700 acres (44%) were non-stocked and lacking adequate seed sources. Of the latter, 34,000 acres was recommended as high priority for planting desirable conifers.

Banks, Wayne G., and Myron D. Ostrander. 1952. **The southwestern Maine fire area—4 years later.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Res. Note 18, 4 pp.

Four years after the 1947 fires in southwestern Maine only 5% of the burned area was completely unstocked but 16% had less than 40% stocking. Of the area stocked 40% or more with seedlings, only 14% was stocked with white pine and only on 3% of this area were the white pines dominant. White pine should be encouraged by cultural operations where it is already present but it does not seem advisable to plant pine until a crop can be made from the hardwoods now on the area.

Beall, H. W. 1934. **Diurnal and seasonal fluctuations of fire hazard in pine forests.** Forestry Chron. 10: 209.

In periods of good weather, fire hazard is greatest between 2 and 4 o'clock in the afternoon and lowest between 4 and 6 in the morning at the Petawawa Forest Experiment Station. Strong winds throughout the day cause a marked change in the diurnal hazard curve. Seasonal variation in hazard of pine stands is small compared to that of other forest types.

Cook, D. B., and S. B. Robeson. 1945. **Varying hare and forest succession.** Ecology 26: 406-410.

Observations on a population of varying hare or snowshoe rabbit *(Lepus americanus)* on Valcour Island, N. Y., indicate considerable selectivity in browse. White and red pine and white spruce seedlings less than 4 feet tall were killed outright; larger trees were trimmed as high as the hares could reach. It seems likely that the number of hares is kept down in the Northeast by the lack of low, dense coniferous cover; but the extensive coniferous plantations on abandoned farmlands may materially alter the situation, and the relation of the varying hare to forest succession may assume increasing importance.

Cope, J. A. 1925. **Grazing in pine plantations.** Jour. Forestry 23: 297-299.

In reference to Stickel and Hawley (1924), it is argued that there is no evidence that grazing reduces fire hazard and that, as shown in southern New York, 90% of the plantation will be ruined by trampling, if grazing is permitted. It is further pointed out that 2-0 white pine stock can compete as well as 2-1 stock with grass and weeds, even though the latter are knee-high.

Corson, C. W., and E. G. Cheyney. 1928. **Injury by rabbits to coniferous reproduction.** Jour. Forestry 25: 539-543.

Black spruce, balsam fir, and white pine (in the order named) were the least susceptible of the native conifers to rabbit feeding. On some plots 100% of the terminal and lateral buds were taken. Damage is greatest in late winter, near swamps, and in years just preceding a rabbit plague.

Craig, J. W. 1940. **Crow damage to conifers.** Jour. Forestry 38: 969.

Perching by the American or carrion crow on Scots, red, and white pine was observed to cause breakage or distortion of the terminal shoots and branches.

F(isher), R(ichard) T. 1918. **Second-growth white pine as related to former uses of the land.** Jour. Forestry 16: 253-254.

Suggests that the silvical and historical evidence in old-field white pine lots in central New England support the view that grazing is beneficial for pine reproduction if it is properly regulated.

Gottlieb, A. W. 1928. **Relation between subcortical temperatures and size of white pine (*Pinus strobus*) slash.** Ecology 9: 243-248.

To determine the relationship between the size of white pine slash and temperatures under the bark, a series of readings was made with a system of thermocouples. Sticks 4 to 6 inches in diameter reached the highest temperature. The variation indicates that temperature may be an imporant factor in the rate of decomposition of different sizes of slash.

Hosley, N. W. 1928. **Red squirrel damage to coniferous plantations and its relation to changing food habits.** Ecology 9: 43-48, illus.

During periods of deep snow when the red squirrels' usual food supply is cut off. they eat the buds of some conifers, thereby retarding the normal growth of the tree. With white pine, the squirrels clip the terminal shoots. Scotch pine apparently suffers most, with Norway spruce and white pine close behind. Intensity of injury varies directly with snow depth.

Krefting, Laurits W., and Joseph H. Stoeckeler. 1953. **Effect of simulated snowshoe hare and deer damage on planted conifers in the Lake States.** Jour. Wildlife Mangt. 17: 487-494.

Two sets of experiments were carried out in Wisconsin in which the leaders of young red, white, and jack pines and white spruce were clipped one to three times at intervals of 1 or 2 years. Susceptibility was rated in terms of mortality, height loss, and loss of form. Clipping affected height more seriously than mortality and there were no forked trees. The species are listed above in order of increasing resistance. Older trees, especially transplants, were the most resistant.

Lake States Forest Experiment Station. 1934. **Estimating fire damage in the Lake States.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 75, 1 p.

The relative dollar-per-acre value of second-growth stands is given for seven forest types in the Lake States as a guide to estimating total or partial losses due to fire. Such average merchantable values are shown by stand-size classes and three stand-density classes; these values have been discounted to the average age of the respective size classes.

Lake States Forest Experiment Station. 1934. **Relative hazard and estimated cost of protection by forest types—Lake States.** U.S. Forest Serv. Lake States Forest Expt. Sta. Tech. Note 78, 1 p.

The area burned over (in percent) and the cost for effective fire protection for the various types are estimated.

Lutz, H. J. 1930. **Effect of cattle grazing on vegetation of a virgin forest in northwestern Pennsylvania.** Jour. Agr. Res. 41: 561-570.

In a virgin hemlock-beech-white pine-red maple stand, grazing caused direct injury to the smaller vegetation by browsing, breaking, trampling, and pulling of small trees out of the soil. Compared to the ungrazed part of the forest, the grazed area had more seedlings, sprouts, and herbacious vegetation less than a foot high but fewer large seedlings and saplings, especially between 1 and 15 feet in height.

McConkey, Thomas W., and Donald R. Gedney. 1951. **A guide for salvaging white pine injured by forest fires.** U.S. Forest Serv. Northeast. Forest Exp. Sta. Res. Note 11, 4 pp.

From studies of fire-damaged trees on the Massabesic Experimental Forest in Maine, the authors offer some general guides on salvage priority, based on degree of root and crown injury. Completely killed stands should be cut first; then severely root-damaged stands should be cut. Authors suggest 25 or more seed trees (more than 12 inchest d.b.h. with only light root injury) per acre be left after salvage cuttings.

McQuilkin, W. E., and S. Little. 1952. **Deer repellent fails to protect pine seedlings.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Res. Note 15, 4 pp.

The repellent, in which the active ingredients are zinc-dithiocarbamate-amine complex plus polyethylene polysulfide, offered no protection to white pine seedlings in Pennsylvania and very little protection to pitch and shortleaf pine reproduction in New Jersey.

Mitchell, J. A. 1934. **Cover type as a factor in fire control.** Jour. Forestry 32: 96-97.

In Michigan over half of the area burned between 1928 and 1932 was in grass plains or second-growth aspen-birch forest. Only 0.8% of the burn was in second-growth red and white pine stands.

Ninman, H. J., and W. C. Thompson. 1927. **Effect of pasturage on white pine reproduction and on timber quality.** Jour. Forestry 25: 549-554.

In a dense stand of reproduction, nearly 27% of the white pines were injured in some respect by livestock. Injury was proportionately greater where the trees were more scattered. In a dense stand of small pine poles at least 40% of the trees were damaged by livestock. The present practice of over-pasturing the woodlots is highly detrimental to the timber. Neither a good grade of timber nor a high yield can be expected where excessive grazing is practiced.

Nutting, A. D., and John R. McGuire. 1948. **Observations on fire-damaged white pine in southwestern Maine, July 1948.** U.S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 19, 9 pp., illus.

An appraisal of damage 9 months after the forest fires of 1947. In partly burned stands expected signs of mortality were not conspicuous: unscorched crowns were still green; growth of new shoots was apparently normal; and insect attacks had not yet become serious. Discusses conditions influencing the fire damage, incoming reproduction, and stand treatment problems.

Petrides, G. A. 1941. **Observations on the relative importance of winter deer browse species in central New York.** Jour. Wildlife Mangt. 5: 416-422.

Report on browsing by northern white-tailed deer recorded during the winters of 1938-39 and 1939-40 near Ithaca, N. Y. White pine is listed as one of the chief emergency foods.

Prebble, M. L., and R. F. Fytche. 1950. **Value loss through degrade in fire-killed pine.** Canada Dept. Agr. Forest Insect Invest. Bimo. Prog. Rpt. 6 (2): 1-2.

A special study of mill output and grade of jack, red, and white pine lumber from trees killed in a May 1948 fire was made in November 1949. Heartwood decay, which antedated the fire and was responsible for cull or reduced grade, was common in jack and white pine. Post-fire deterioration was caused by larvae of wood-boring beetles and by sap-staining fungi. Value loss in white pine trees that were dying gradually during 1949 averaged only 2.4%. Value loss in white pine killed outright in May 1948 was related directly to the original quality and value of the lumber. The loss was about 12% on logs whose original value was $53 per 1,000 board feet, but the loss increased to 57% in logs that had an original value of $121.

Pryor, L. D. 1940. **The effect of fire on exotic conifers.** Austral. Forestry 5: 37-38.

Two factors that determine the survival of a tree after fire are bark thickness and ability to produce new foliage. Eastern white pine is listed as very susceptible to fire, only 5 others out of 29 being more susceptible.

Society of American Foresters, New England Section. 1929. **Grazing in relation to forestry in New England.** Jour. Forestry 27: 602-608.

Report of a special committee on the silvicultural, regulative, and economic aspects of woodland grazing. No kind of stock can be grazed in the forest without some damage; but damage can be reduced so that it is more than offset by the release of conifers in restocking area. The committee does not forsee the widespread use of grazing as a silvicultural tool, but some woodland owners may be able to use it to advantage.

Spaulding, Perley, and J. R. Hansbrough. 1944. **Decay of logging slash in the Northeast.** U.S. Dept. Agr. Tech. Bul. 876, 22 pp., illus.

Decay of slash was studied in relation to fire hazard. Slash disintegrated in an average of 15 years for hardwoods, 17 years for white pine, and 29 years for red spruce. Under favorable conditions, these times can be shortened by 20%. Fire danger of white pine slash becomes low in about 10 years but is high for the first 5 years.

Stewart, Guy R. 1933. **Forest plantations injured by roosting birds.** Jour. Forestry 31: 421-423, illus.

Defoliation and death of white pine trees in plantations used by large numbers of roosting birds is caused by accumulation of excessive amounts of nitrate nitrogen from bird droppings under the trees. Excessive amounts were found in all soil horizons, so recovery will take a long time. Means to control the birds are suggested.

Stickel, Paul W. 1932. **Weather and forest fire hazard with special reference to the white pine region of central New England.** Mass. Forestry Assoc. Bul. 153, 8 pp., illus.

Under mature white pine and hemlock, hazardous conditions develop much more slowly than in the open and, for equivalent hazard, significant weather elements must be much more severe. Alinement charts are given for estimating fire hazard.

Stickel, Paul W. 1938. **Northeastern forest-fire danger meters.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 25, 4 pp.

A description of seven fire-danger classes developed for white pine, spruce-fir, and mixed northern hardwoods. They are based on air temperature, relative humidity, time since last rain, and wind velocity. Administrative action in preparation for fire-control work is suggesed for each danger class.

Stickel, Paul W. 1940. **The effect of basal-wounding by fire on trees in the Northeast.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 30, 2 pp.

In white pine, two plots were examined annually for 3 years after a fire. Of some 1,300 trees examined, 70% were killed outright and 29% were alive but showed scorching or other injury right after the fire. In 3 years 32% of these injured trees had died and only 36% showed no open fire scar.

Stickel, Paul W., and Ralph C. Hawley. 1924. **The grazing of cattle and horses in pine plantations.** Jour. Forestry 22: 846-860.

In southern New England, regulated grazing in young white and red pine plantations is beneficial. It reduces fire hazard and reduces or eliminates the cost of weeding. Horses are more destructive to pine than cattle, and grazing in winter is more injurious than grazing from March to October. Grazing should be restricted to the period prior to crown closure.

Stickel, Paul W., and Ralph C. Hawley. 1925. **The grazing of cattle and horses in pine plantations.** Jour. Forestry 23: 389-391.

Refers to Cope (1925) and Stickel and Hawley (1924) in defense of the latter article. An example is presented of the intensity of fire in grazed and ungrazed plantations. Although complete destruction of pine plantations can result from overstocking with animals and on localized areas around water holes, salting grounds, and paths of travel, this damage can be held to a negligible amount by proper regulation of the grazing animals.

Sweetman, H. L. 1944. **Selection of woody plants as winter food by the cottontail rabbit.** Ecology 25: 467-472.

White pine was among 25 species seriously damaged by cottontails on the 3-acre lot examined. There were 100 woody species present.

Wright, J. G. 1932. **Forest fire hazard research.** Forestry Chron. 8: 133-151, illus.

From results of calorific and combustion studies on white and red pine duff, a method of rating inflammability of the white and red pine forest type in eastern Ontario and western Quebec has been worked out. It is based on the rate and intensity of duff burning when ignited with a match. This is also equated with the duff moisture content. Weather factors were also correlated with duff inflammability. The development of these studies and their results are summarized.

Wright, J. G. 1933. **Forest-fire hazard tables for mixed red and white pine forests.** Canada Forestry Branch, Forest-Fire Hazard Paper 3, 10 pp., illus.

These tables are designed for computing (from the daily record of rainfall, rate of evaporation, and relative humidity of the air) the degree of fire hazard that will prevail each day in mixed red and white pine forests in eastern Ontario and western Quebec.

Young, Vernon A. 1936. **Edaphic and vegetational changes associated with injury of a white pine plantation by roosting birds.** Jour. Forestry 34: 512-523, illus.

Starlings roosting during the fall of 1933 and 1934 mechanically injured the leaves during their roosting activities and deposited large amounts of droppings on the forest floor. Droppings increased nitrate, phosphorus, and potassium and apparently upset the physiology of the trees so that they died in a short time. In addition, some 68 species of plants with hard seed coats, including Ribes, germinated on the forest floor and established intense competition. These seeds were carried in the droppings.

DISEASES
White Pine Blister Rust

Anderson, Olof Campbell. 1939. **A cytological study of resistance of viking currant to infection by *Cronartium ribicola*.** Phytopath. 29: 26-40, illus.

Leaves of highly-resistant Viking, a Norwegian Red Dutch currant of unknown origin but probably in part derived from *Ribes petraeum,* were compared with those of three susceptible *Ribes* (*R. nigrum, R. sativum* hybrid var. American Red Dutch, and *G. hirtella*), all of which were similarly inoculated during 2 years with *C. ribicola.* Cytological investigation revealed that infection occurred through the stomata in young unhardened Viking leaves, but the resulting sparse hyphae died before the parasite could develop or produce spores.

Colley, Reginald H. 1918. **Parasitism, morphology, and cytology of *Cronartium ribicola*.** Jour. Agr. Res. 15: 619-659, illus.

The literature and the results of original studies are summarized, and the interrelations between the fungus and its hosts are discussed. The morphology of the mycelium, pycnia, and aecia on pine; and of the mycelium, uredinia, and telia on Ribes are described. So too are the formation and germination of the related spores. The cytology of the various fungal organs is explored, with emphasis on nuclear phenomena.

Cooper, William S. 1922. **The ecological life history of certain species of Ribes and its application to the control of the white pine blister rust.** Ecology 3: 7-16.

Outlines the successional development and climax vegetation of New England and the Adirondacks and the role of three native Ribes species in this flora. The most common Ribes habitat was in pastures and orchards, where they thrived. Next was mixed second-growth woodland, while old-growth forest had very few Ribes. Birds, especially those of open ground, feed on and spread Ribes seed. Invasion of open areas by forest reduces the abundance and weakens the Ribes progressively until they die out.

Detwiler, S. B. 1933. **General aspects of the white pine situation.** Jour. Forestry 31: 514-521.

As an aid to policy decisions, the author reviews the white pine situation since the advent of the white-pine blister rust: forest conditions, silvical characteristics of white pine, suitability for management, economic value, blister rust control problem, and costs. Urges that production of white pine be encouraged and that blister rust control be stepped up.

Filler, E. C. 1933. **Blister rust damage to northern white pine at Waterford, Vt.** Jour. Agr. Res. 47: 297-313.

Infection was greater on the larger-crowned trees, but death was greater among the less vigorous intermediates. Pines of all sizes from seedlings to merchantable trees were attacked.

Filley, W. O., and H. W. Hicock. 1922. **Control of white pine blister rust in Connecticut.** Conn. Agr. Expt. Sta. Bul. 237: 305-326, illus.

The history and nature of white-pine blister rust and its life cycle, the importance of white pine as a forest tree, state legislation, and early control work of Ribes eradication (1909-21). Also discusses the national situation, future control, new studies of the rust, and a survey of white pine in Connecticut.

Fivaz, A. E. 1931. **Longevity and germination of seeds of Ribes, particularly *R. rotundifolium*, under laboratory and natural conditions.** U.S. Dept. Agr. Tech. Bul. 261. 40 pp., illus.

Laboraory tests of *Ribes rotundifolium* and *R. cynosbati* seeds show that best germination is obtained in a neutral medium with a daily temperature range from 10 to 25° C. Field studies of Ribes in relation to stand history in the Adirondacks indicate that Ribes seeds may lie dormant in the soil for periods of as much as 70 years and germinate when distrubances such as windthrow, fire, or logging create the required variation in daily temperature.

Fracker, S. B., and R. A. Sheals. 1933. **The protection of forest nurseries from white pine blister rust infection.** Jour. Econ. Ent. 26: 641-648.

Changes in quarantine regulations relating to the shipment of nursery stock are reviewed. They make it permissible to ship anywhere in the country from nurseries where a protection zone 1,500 feet wide is kept clear of Ribes by annual working. In addition, *R. nigrum* must be destroyed in a zone extending 1 mile from the nursery.

Hahn, Glenn Gardner. 1943. **Blister rust relations of cultivated species of red currants.** Phytopath. 33: 341-353.

Cultivated red currants, usually lumped together in treating blister rust, actually fall into three groups, by origin from three European species. The small group related to *Ribes petraeum* is immune to blister rust. *R. rubrum* typifies another small group that is highly resistant to infection. The group descended from *R. sativum* is highly susceptible to infection.

Hirt, Ray R. 1935. **Observations on the production and germination of sporidia of *Cronartium ribicola*.** N.Y. State Col. Forestry Tech. Pub. 46, 25 pp., illus.

Discusses the results of controlled experiments on the optimum conditions for spore germination: a temperature of 12 to 16° C. and a relative humidity of 96 to 100% for teliospores, and a temperature of 12 to 18° C. and a relative humidity of 100% (direct contact with water) for sporidia. Exposure to direct sunlight for 8 hours did not kill teliospores but did lengthen the time required to produce sporidia. The same treatment killed sporidia but they remained viable during 8 hours of daylight if not directly exposed to sunlight. When sporidia germinated they produced either secondary sporidia or true hyphae.

Hirt, Ray R. 1936. **The progress of blister rust in planted northern white pine.** Jour. Forestry 34: 506-511, illus.

On each day from July 14 to September 29, 1927, 20 different nursery-grown white pine seedlings were exposed to blister rust infection for 24 hours. They were then planted out in a rust-free area at Warrensburg, N. Y. About 16% of them became infected—most of them during 2 short periods. Production of aeciospores on the infected trees began 3 years later and continued for at least 5 years but only a small proportion of infected trees produced them. Some infected trees will survive but the mortality was much higher than mortality in trees not infected. The proportion of infected trees dying increased yearly during the 8-year observation period.

Hirt, R. R. 1938. **Relation of stomata to infection of *Pinus strobus* by *Cronartium ribicola*.** Phytopath. 28: 180-190, illus.

Stomata probably have very little significance. No germ tubes were seen to enter the needles through the stomata but they did penetrate directly through the walls of the epidermal cells. Germ tubes from primary sporidia require approximately 10 hours of favorable weather to reach the mesophyll.

Hirt, Ray R. 1939. **Canker development by *Cronartium ribicola* on young *Pinus strobus*.** Phytopath. 29: 1067-1076, illus.

Report on studies made under natural conditions in the Adirondacks and in central New York. It should be possible by September of each year to estimate the intensity of infection from the preceding year. The average time for branch cankers to extend to the stem was 3 years, thus making it possible to detect and remove infected branches before the stem is invaded. Trees usually died 2½ to 6½ years after stem infection from a branch canker.

Hirt, Ray R. 1939. **The development of blister rust on young planted northern white pine.** Jour. Forestry 37: 967-969.

A single exposure of young white pines to telia-bearing bushes of European black current for 12 or 24 hours under natural conditions resulted in 4% of the trees becoming infected. Continuous exposure to the same Ribes throughout a summer resulted in as much as 69% infection. Within 5 years after infection, about one-third of the diseased trees died.

Hirt, Ray R. 1940. **Relative susceptibility to *Cronartium ribicola* of 5-needled pines planted in the East.** Jour. Forestry 38: 932-937.

Eleven species were planted and exposed to infection in a controlled experiment under natural environmental conditions in the Adirondacks and in central New York. White pine was found to be more susceptible than five other species but less susceptible than *Pinus monticola* and *P. flexilis*.

Hirt, R. R. 1942. **The relation of certain meteorological factors to the infection of eastern white pine by the blister rust.** N.Y. State Univ. Col. Forestry Tech. Pub. 59, 65 pp.

The minimum time required for pine infection under optimum conditions of moisture and temperature was found to be 11.5 hours, but the amount of infection increased after 19.5 hours. The optimum temperature range was appriximately 50-65° F., and a constant temperature level of 68-69° F. was sufficient to inhibit infection. Rain was more important than either fog or dew as the source of moisture favorable to infection of eastern white pine, although fog and dew also tended to produce favorable conditions. Pronounced pine infection was restricted to relatively few periods when favorable weather happened to coincide with suitable stages in the development of the rust.

Hirt, Ray R. 1944. **Distribution of blister-rust cankers on eastern white pine according to age of needle-bearing wood at time of infection.** Jour. Forestry 42: 9-14.

Intensive studies of infection and canker development have shown that the majority of cankers develop on needle-bearing wood that was 1 year old at the time of infection. This was equally true of potted trees and those in undisturbed natural stands.

Hirt, Ray R. 1948. **Evidence of resistance to blister rust by eastern white pine growing in the Northeast.** Jour. Forestry 46: 911-913.

A brief progress report on the selection and testing of white pine at Syracuse, N. Y. Apparently resistant stock from various sources has been transplanted to Syracuse for testing. A number of trees appear to be immune or resistant, but efforts to propagate them by cuttings or grafts have not been very successful so far.

Hubert, Ernest E. 1935. **Observations on *Tuberculina maxima*, a parasite of *Cronartium ribicola*.** Phytopath. 25: 253-261, illus.

A brief review of European use of the so-called purple mold as a control of the white-pine blister rust introduces studies made in Idaho on this rust parasite. Field experiments and laboratory tests indicate a slow-growing and sensitive organism not easily established on its host. Once established, the purple mold is capable of slow spread and inhibits aeciospore production on blister rust cankers. The possibilities of its use as a biological control agency are remote.

Johnson, Albert G. 1947. **Some effects of 2,4-D on pines.** Jour. Forestry 45: 288-289.

Standard-strength solutions of 2,4-D were found to be highly effective in the destruction of wild black currant (*Ribes americanum*) in Wisconsin.

Lindgren, Ralph M., and A. Dale Chapman. 1933. **Field inoculations of *Pinus strobus* with sporidia of *Cronartium ribicola* in Minnesota.** Phytopath. 23: 105-107.

White pines, 3 to 7 years old, were inoculated with sporidia from *Ribes nigrum* and *R. cynosbati*. The former affected 23 branches on 8 out of 9 trees and the latter 1 branch on 1 out of 9 trees.

McCubbin, W. A. 1918. **Dispersal distance of urediniospores of *Cronartium ribicola* as indicated by their rate of fall in still air.** Phytopath. 8: 35-36.

The urediniospores averaged about 1½ minutes to fall 8 feet in still air, but many of the heavier ones took as long as 5 minutes. This means that dispersal distance for the spores should be considered in terms of miles, rather than of yards, as previously.

McCubbin, W. A., and G. B. Posey. 1917. **Development of blister rust aecia on white pines after they had been cut down.** Phytopath. 7: 391-392.

Observations at Cooks Town, Ontario, and Kittery Point, Maine, show that cankers on felled trees produce aeciospores prolifically, sometimes under the bark in drier stems. All infected cut material should be burned for effective sanitation.

McGinn, W. K., and A. G. Davidson. 1953. **Studies of white pine blister rust in Nova Scotia.** Forestry Chron. 29: 267-272.

In sample-plot studies no relationship was found between Ribes establishment and degree of cutting. Uncut stands where white pine predominates show evidence of producing a future pine crop. Forest types supporting white pine appear to offer the best opportunities for pine reproduction where clearcutting has given the stand maximum opening. Results of the study to date do not show that blister rust is a major factor in retarding the establishment of white pine regeneration.

McIntyre, H. L. 1942. **White pine blister rust control policies in New York State.** Jour. Forestry 40: 782-785.

A resumè of blister rust activities in New York from 1920 through 1940. Effectiveness of control work has been continually improved. In dense woodlands or swamp areas where the pine is screened from Ribes a 50-foot, instead of the original 900-foot, protective zone is covered and in more open woodlands the width of the strip is 200 feet. The possession of European black currant is prohibited by law but the destruction of cultivated red currants beyond 300 feet from pine has been discontinued.

Martin, J. F. 1937. **Protect white pine from blister rust.** U.S. Dept. Agr. Misc. Pub. 22 (rev.), 8 pp., illus.

First issued as Misc. Circ. 40 in July 1925 and as Misc. Pub. 22 in 1928 (revised 1931 and 1937). States the importance of white pine, spread of blister rust disease, damage to pines, and control measures. Four of the eight figures illustrate, in color, the spread of blister rust and pine damage. This publication proved of great value in alerting the public to the dangers of and methods of control for this disease.

Martin, J. F. 1938. **Some economic aspects of white pine blister rust control.** Jour. Forestry 36: 986-996, illus.

Cost of Ribes eradication is affected by many factors: accessibility, topographic features, and ground cover; rates, quality, and source of labor; length of work day; and abundance of Ribes. Where pine is economically important, the costs are justified. As Ribes is intolerant, intensive control is necessary only in the early stages of succession.

Martin, J. F. 1940. **The application of surgery to blister rust infected trees of ornamental value.** Natl. Shade Tree. Conf. Proc. 16: 113-120.

The disease is described briefly and directions are given for the surgical treatment of infected pines. Under arboricultural conditions the cost of such treatment is often less than that of removing or replacing the trees. Surgical treatment is useless unless Ribes are cleared from the neighborhood to prevent re-infection.

Martin, J. F. 1944. **Ribes eradication effectively controls white pine blister rust.** Jour. Forestry 42: 255-260.

In white pine forest areas the blister rust can be effectively controlled by reducing the Ribes to an average of 25 feet of live stem or less per acre and subsequently keeping these plants suppressed. Complete eradication of Ribes can be justified only in pine stands of aesthetic or recreational importance, or forest-tree nurseries.

Martin, J. F., A. E. Stone, and R. A. Sheals. 1920. **How to distinguish and combat the white pine blister rust.** R. I. Bd. Agr. Ent. Dept. Bul. 1, 38 pp. (In coop. with U.S. Dept. Agr. Bur. Plant Indus.)

A discussion of the blister rust fungus and its mode of attack on white pine; contains good photographs of the stages of the fungus on pines and the alternate host Ribes. Also illustrates and discusses other tree diseases and insect injuries that might be mistaken for white pine blister rust. Control of the blister rust by Ribes eradication and the regulations for planting of 5-needled pines, currants, and gooseberries are given for Rhode Island.

Mielke, J. L. 1935. **Rodents as a factor in reducing aerial sporulation of *Cronartium ribicola*.** Jour. Forestry 33: 994-1003, illus.

Data are given on extent and results of rodent-feeding, both in eastern and in western North America. The removal of infected bark by rodents sometimes results in a considerable reduction in volume of aesciospores.

Mielke, J. L. 1943. **White pine blister rust in western North America.** Yale Univ. School Forestry Bul. 52, 155 pp., illus.

A thorough review of the whole blister rust problem, aimed particularly at western conditions, but much of it also applicable in the East. Included is material on origin and introduction of blister rust, white pine species, the rust on pines, the rust on Ribes, scouting for rust, rust situation in the West, and factors in the spread of rust.

Moir, Stuart W. 1924. **White pine blister rust in Western Europe.** U.S. Dept. Agr. Bul. 1186, 32 pp.

Blister rust was first found about 1860 in the Baltic Provinces of Russia. From 1880 to 1900 it was noted with increasing frequency in Western Europe. Most white pine plantings are 80% or more infected. Sugar, western white, limber, and Mexican white pines appear as susceptible to blister rust as white pine. Cultivation of black currant and gooseberries is widespread, and the rust on the former is particularly virulent. The cultivated Ribes are more highly regarded economically than are the exotic white pines, so effective control is unlikely.

Muller, R. 1936. ***Pinus strobus* rediviva.** Forstarchiv 12: 253-262.

In a discussion of the report of the white pine committee of the Deutscher Forstverein and von Tubeuf's criticism of it, it is concluded that white pine is a valuable tree for German silviculture, in spite of the blister rust, and that it should continue to be grown, under suitable conditions.

Perry, C. C. 1929. **Cost of blister rust control work. A "carrying charge" in the production of white pine.** Jour. Forestry 27: 50-54, illus.

Discussion of the cost of initial eradication of Ribes and periodic maintenance work in New England. Initial costs were 15.3¢ per acre on 4.7 million acres. Reworking costs are estimated at about half of initial costs. Computations show that it costs 12 to 40¢ per acre to protect pine, depending on the size of the blocks protected.

Pierce, R. G. 1917. **Early discovery of white pine blister rust in the United States.** Phytopath. 7: 224-225.

The earliest known collection of blister rust in the United States was made by Samuel N. Baxter from a nursery near Philadelphia in April 1905. The specimen was sent to the U. S. Department of Agriculture, where Mrs. F. W. Patterson, mycologist, identified it.

Posey, G. B., and E. R. Ford. 1924. **Survey of blister rust infection on pines at Kittery Point, Maine, and the effect of Ribes eradication in controlling the disease.** Jour. Agr. Res. 28: 1253-1258.

A patch of black currant (*Ribes nigrum* L.) plants introduced from England in 1897 created a primary infection center and caused infection of pine in the surrounding stands the same year. The annual rate of infection increased 20 times from 1901 to 1916. Destruction of all Ribes prevented the occurrence of new pine infection and permitted natural restocking with disease-free seedlings.

Radulescu, Theodor. 1937. **Beiträge zur Kenntnis der Baumkrankheiten. 1. Untersuchungen über den Blasenrost der Weymouthskiefer.** Forstwiss. Centbl. 59 (19): 597-609, illus.

White pine shows wide individual variation—apparently hereditary—in susceptibility to blister rust. Of 73 trees felled in thinning a 0.14-hectare plot in a 52-year-old stand in Upper Bavaria, only 25 were infected, although the infection began 32 years before. In Upper Bavaria white pine stands, even when exposed to infected Ribes, may grow for decades without enough infection to necessitate cutting, and a reasonably full stand will reach maturity.

Riker, A. J., T. F. Kouba, W. H. Brener, and L. E. Byam. 1943. **White pine selections tested for resistance to blister rust.** Jour. Forestry 41: 753-760, illus.

Ten thousand seedlings and 1,000 veneer grafts from some 150 selected white pine, which had shown no blister rust after 15 to 20 years natural exposure to infected Ribes, were tested by both natural and artificial inoculation. Among the progeny from the first 63 selected trees, inoculated in September 1941, about 5% of the grafts and up to 100% of the seedlings showed infection.

Riker, A. J., T. F. Kouba, and B. W. Henry. 1947. **The influence of temperature and humidity on the development of white pine blister rust on Ribes leaves.** (Abs.) Phytopath. 37: 19.

Studies of the influence of environment on infection of Ribes by *Cronartium ribicola* in the greenhouse (controlled environment) and at the Wisconsin blister-rust nursery substantiate the observations (1) that telia seldom develop well on most species during hot weather, and (2) that hot weather improves the chances for white pine to escape infection.

Riley, J. E., Jr. 1930. **White pine blister control in Connecticut.** Conn. Agr. Expt. Sta. Bul. 314: 455-477.

A revision and up-dating of Conn. Agr. Expt. Sta. Bul. 237 (Filley and Hicock 1922), with added discussion of control methods, organization, cooperation, nursery sanitation, black currant eradication, status of control, and effectiveness. Describes insects and diseases often mistaken for blister rust, identification of Ribes species, and where to plant white pine.

Rusden, P. L. 1952. **Blister rust damage at Waterford, Vermont.** Jour. Forestry 50: 545-551, illus.

This longest available series of blister rust observations continued for 20 years in a heavily infected 2½-acre stand of merchantable white pine. Measurements of tree and volume losses among crop and non-crop trees at 5-year intervals are presented. Loss of volume (including potential growth on killed trees) is computed. The analysis shows that during the 20-year period the stumpage value per acre was cut about in half by blister rust mortality.

Schmid, R. 1954. **Über die histologische Spezialisierung von Blatt- und Rindenpilzen, mit besonderer Berücksichtigung ihrer Beziehungern zum Phloem.** Phytopath. Ztschr. 21: 407-432.

Describes, with photomicrographs and drawings, the development of the attack of various fungi in the tissues of the host. *Cronartium ribicola* attacks primarily the parenchyma and ray cells in pine. It grows readily in the sieve tubes and penetrates their walls. The harmful effect is specially noticeable in degeneration of the cambium. In later stages the bark tissue dies and the hyphae spread from the rays into and between the tracheids.

Snell, Walter H. 1919. **Observations on the relation of insects to the disemination of *Cronartium ribicola*.** Phytopath. 9: 451-464.

Many species of insects were found, some of them on both hosts, bearing aeciospores, urediniospores, and sporidia. The spread of the rust by insects from pine to Ribes or vice versa may be infrequent and accidental, but the spread of the uredinial stage upon Ribes probably occurs with some regularity.

Snell, Walter H. 1920. **Observations on the distance of spread of aeciospores and urediniospores of *Cronartium ribicola*.** Phytopath. 10: 358-364.

It is shown that the aeciospores of *C. ribicola* can be blown more than 1¼ miles and infect Ribes. Dry weather prevented a wide distribution of the disease by urediniospores during the summer of 1918 in Essex County, N. Y.

Snell, Walter H. 1931. **Forest damage and the white pine blister rust.** Jour. Forestry 29: 68-78, illus.

A detailed study of eight plots in New York revealed that there is no correlation between percentage of blister rust infection, mortality, and ultimate board-foot loss. Number of trees left, their crown development, other damage, branchiness, spacing, and the presence of trainers must also be considered.

Snell, Walter H. 1941. **The relation of cultivated red currants to the white pine blister rust in New York.** Jour Forestry 39: 859-867, illus.

A study was made in New York and New England of 72 cases where cultivated red currants grew within 900 feet of planted or native pine. There was very little evidence of infection by sporidia from the red currants and no evidence of damage to the pine, even when the currants were within 60 feet of the pine.

Snell, Walter H. 1942. **The production of sporidia of *Cronartium ribicola* on cultivated red currants in relation to infection of white pine.** Amer. Jour. Bot. 29: 506-513.

From data on number of leaves, total leaf areas, number of tilia, and number of sporidia per bush, it is shown that a garden row of red currants will produce at best only a small fraction of the sporidia produced by wild gooseberries and an even smaller fraction of the number produced by black currants.

Spaulding, Perley. 1922. **Investigations of the white pine blister rust.** U.S. Dept. Agr. Bul. 957. 100 pp., illus.

Presents all the essential facts known at the time about white pine blister rust, as determined from research. Covers origin and distribution, hosts, life history, overwintering, important dates in the life history, and control. A list of 180 references is given.

Spaulding, Perley. 1925. **A partial explanation of the relative susceptibility of the white pines to the white pine blister rust (*Cronartium ribicola* Fischer).** Phytopath. 15: 591-597.

Eastern white pine is susceptible to blister rust but not so much so as western white pine and a number of other species. There appears to be a general relation between degree of susceptibility and (1) the number of years leaves persist, and (2) the relative numbers of stomata on the leaves. Phloem thickness may also be a factor in susceptibility—the thicker phloem of the western pine seems more suitable for vegetative growth of the rust.

Spaulding, Perley. 1926. **The white pine blister rust in Germany.** Jour. Forestry 24: 645-652.

A review of the ideas of Harrer and Tubeuf (1914-1926) regarding the extended use, planting and protection policies, values, and relative blister rust susceptibility of the native and exotic 5-needled pines in Germany. Major policy questions concern the species to plant and whether or not blister rust protection is possible, especially with *Pinus strobus, P. monticola,* and *P. lambertiana.* Use of rust-resistant currants for cultivation is suggested. The author favors limiting the areas in which white pines may be grown and applying known methods of blister rust control within such areas.

Spaulding, P. 1929. **White-pine blister rust: a comparison of European with North American conditions.** U.S. Dept. Agr. Tech. Bul. 87, 59 pp.

A report on an investigation of the white pine blister rust *(Cronartium ribicola)* in various countries of northern and western Europe, in which a comparison was made between the conditions that influence the disease. Cultivated Ribes are common in Europe, and *R. nigrum,* a favorite, is found practically everywhere that the species will grow. Practically all the white pine infections seen in Europe were considered due to this host.

Spaulding, Perley, and Annie Rathbun-Gravatt. 1925. **Conditions antecedent to the infection of white pines by *Cronartium ribicola* in the northeastern United States.** Phytopath. 15: 571-583, illus.

The conditions necessary for the infection of white pines are many, and some of them are not known. It is known that there must be a period of sufficient moisture to germinate the teliospores, and that this must be followed by a period of high humidity for infection to take place. Temperaure appears not to be so important. Questions that need investigation are suggested.

Spaulding, Perley, and Annie Rathbun-Gravatt. 1925. **Longevity of the teliospores and accompanying uredospores of *Cronartium ribicola* Fischer in 1923.** Jour Agr. Res. 31: 901-916, illus.

Teliospores and accompanying uredosproes from eight Ribes hosts were stored under outdoor conditions and were germinated at 7-day intervals. The required germination period increased directly with duration of storage. The shortest life was 19 days for one collection from *Ribes rotundifolium.* Teliospores on *R. nigrum* lived 87 days and were germinating well when the tests ended.

Spaulding, Perley, and Annie Rathbun-Gravatt. 1926. **The influence of physical factors on the viability of sporidia of *Cronartium ribicola* Fischer.** Jour. Agr. Res. 33: 397-433, illus.

A pioneer study of the physiology of white pine blister rust spores. Methods of study and the effect on sporidial viability of drying, alternate wetting and drying, relative humidity changes, icing, sunlight, and constant wetting are described in detail. All factors except icing tended to decrease germination.

Stewart, F. C. 1906. **An outbreak of the European currant rust (*Cronartium ribicola*).** N.Y. State Agr. Expt. Sta. Tech. Bul. 2: 61-74.

Report on the discovery, in September 1906, of the fungus that causes white pine blister rust on currants (Ribes). Describes the fungus, and lists its geographical distribution and economic importance in Europe. Indicates the possible source of the outbreak at the New York State Agriculture Experiment Station, Geneva, N. Y. Discusses the control methods used and the danger to *Pinus strobus* and other 5-needled pines in North America. A bibliography of 67 references is given.

Temple, C. E., and H. E. Yost. 1943. **White pine blister rust control in Maryland.** Univ. Md. Ext. Serv. Hort. Dept. Bul. 98, 23 pp., illus.

Outlines the extent and value of white pine in Maryland, the history and spread of the white pine blister rust, the fungus life cycle, the characteristic appearance of the disease in both pine and Ribes, the extent of the damage, and the methods of control. Control by Ribes removal now covers most of the better stands of white pine in the State. Further reworking at 3- to 5-year intervals will be less costly. The State regulations for control of this disease are given.

Tubeuf, Carl von. 1933. **Studien über Symbiose und Disposition sowie über Vererbung pathologischer Eigenschaften unserer Holzpflanzen. 4. Disposition der fünfnadeligen Pinus-Arten einerseits und der verschiedenen Ribes-Gattungen, Arten, Bastarde und Gartenformen anderseits für den Befall von *Cronartium ribicola*.** Zeitschr. Pflanzenkrank. 43: 433-471.

Records inoculation tests of *Cronartium ribicola* on some 400 species, varieties, and hybrids of Ribes and Grossularia. Only a small number proved to immune, including 9 cultivated varieties and hybrids of Ribes and 11 species or varieties of Grossularia. Discusses susceptibility of the 5-needle pine species to blister rust, with a key to the species.

United States Bureau of Entomology and Plant Quarantine. 1949. **White pine blister rust control. Manual of field procedures and general information—Northeastern Region.** U.S. Bur. Ent. and Plant Quar., 112 pp., illus.

Describes white pine blister rust and its importance, field procedures for control area surveys, scouting, Ribes eradication, and work inspection. Includes descriptions of the host species and of other important pests of white pine.

Van Arsdel, E. P., A. J. Riker, and R. F. Patton. 1953. **Microclimatic distribution of white pine blister rust in southwestern Wisconsin.** Phytopath. 43: 487-488.

In southwestern Wisconsin, certain topographic features and vegetation patterns that lowered temperatures and increased humidities were correlated with blister rust distribution. In culture tests a constant temperature of 20° C. or less was optimum for all spores. Sites that had a saturated atmosphere several hours a day longer in late summer or fall than surrounding areas appeared to favor spore production.

Van Vloten, H. 1941. **Korte mededeeling over de proef met *Pinus strobus* van verschillende herkomst uit Noord-Amerika.** Nederland. Boschbouw Tijdschr. 14: 345-346.

Preliminary results from a test of 43 provenances of white pine exposed to as great a chance as possible of infection by *Cronartium ribicola* showed that although severe infection could be found in all provenances, not all developed aecia, and the percentage of plants showing aecia varied in different lots from 0 to 72. Only continued observations can determine whether the differences so far observed are in fact differences of natural resistance.

York, Harlan H., and Walter H. Snell. 1922. **Experiments in the infection of *Pinus strobus* with *Cronartium ribicola*.** Phytopath. 12: 148-150.

In infection experiments at North Conway, N. H., it was determined that sporidia become fully developed in 5 to 6 hours after dry teliospores are placed in favorable germination conditions. It takes at least 18½ hours of constantly favorable conditions for infection to occur on pine in close proximity to infected Ribes. Infection occurs on the seedling pines 12½ hours after the viable sporidia reach the needles.

York, H. H., W. H. Snell, and Annie Rathbun Gravatt. 1927. **The results of inoculating *Pinus strobus* with the sporidia of *Cronartium ribicola*.** Jour. Agr. Res. 34: 497-510, illus.

Inoculation experiments indicated that seedlings of all ages may be infected, that 1- and 2-year-old needles are equally susceptible, and that cankers developed on wood formed during the year of infection and during the preceding year. Mortality was higher among infected seedlings than among those not infected; seedlings could be killed within a year of inoculation.

Other Diseases

Abbott, F. H. 1915. **The red rot of conifers.** Vt. Agr. Expt. Sta. Bul. 191, 20 pp., illus.

The red rot caused by *Fomes pini* is most serious in unthinned pure white pine stands. Prevention is best effected by thinning, removal of diseased trees, and destruction of fruiting bodies. The weight and breaking and crushing strength of infected wood are reduced roughly in proportion to the permeation of the wood by the fungus.

Baldwin, Henry I. 1954. **Needle blight in eastern white pine.** U.S. Dept. Agr. Plant Dis. Rptr. 38: 725-727.

Reviews the history and symptoms of this blight. Primary symptom is a reddish-brown appearance of the foliage, usually extending from the tip back about one-third of the needle's length. Results of a survey made in southern New Hampshire in 1954 indicate that the blight is seldom fatal and is not associated with insects or disease.

Berk, S. 1948. **Inoculation experiments with *Polyporus schweinitzii*.** Phytopath. 38: 370-377.

Polyporus schweinitzii is very destructive to white and red pine planted on abandoned fields in New York State. Inoculation and fungus culture tests were made to determine whether the widespread occurrence of the disease was due to dissemination of spores from outside, or to persistence of the organism as a saprophyte in the soil or weakly parasitic on the roots of hardwood seedlings and herbaceous plants. Results indicate that *P. schweinitzii* is not capable of parasitizing roots of hardwood seedlings and grows well in autoclaved soils or duff. Probably *P. schweinitzii* becomes parasitic only when the host is growing under very favorable conditions.

Campana, Richard J. 1954. ***Corticium galactinum* does not cause white pine needle blight.** U.S. Dept. Agr. Plant Dis. Rptr. 38: 297-303.

The reported association of this fungus with the disease had led to speculation that its primary effect was the destruction of feeding rootlets. The author's observations give no indication that this fungus invades the roots; attempts to isolate it from inoculated roots were unsuccessful.

Cox, R. S. 1953. **Etiology and control of a serious complex of diseases of conifer seedlings.** (Abs.) Phytopath. 43: 469.

A tree disease complex on conifer seedlings in a Delaware nursery was due primarily to a soil-borne fungus, *Cylindrocladium scoparium*, causing damping-off, root rot, stem canker, and needle blight. White pine seedlings are seriously damaged under conditions of high humidity. Excellent control was obtained with formaldehyde for soil treatment and Bordeaux mixture plus a sticker spreader as a foliar spray applied monthly during the growing season.

Cox, R. S. 1954. ***Cylindrocladium scoparium* on conifer seedlings.** Del. Agr. Expt. Sta. Tech. Bul. 301, 40 pp., illus.

See above.

Dana, S. T. 1908. **Extent and importance of the white pine needle blight.** U.S. Forest Serv., 4 pp.

The disease was first reported at Concord, N. H., where a few trees showed the symptoms in 1905. By spring 1907 the disease was widespread, covering nearly all of the white pine region in New England. The symptoms are a reddish-brown coloration of the needle tips on the current year's growth only. Trees of all ages and sizes and conditions are affected, but trees are damaged as single individuals scattered through the woods rather than as groups of trees.

Davidson, Ross W., and Frances Lombard. 1954. **Brick red stain of Sitka spruce and other wood substrata.** Phytopath. 44: 606-607, illus.

The recently described *Ascocybe grovesii* is the fungus that was associated with brick red stain of airplane spruce. Its growth on other wood substrata such as white pine and its growth in pure culture on several media indicates it is not restricted to particular substrata.

Davis, W. C., G. Y. Young, and L. W. Orr. 1939. **Needle droop of pine.** Jour. Forestry 37: 884-887.

Abnormal needle drooping of the current season's growth of red pine, and occasionally of white pine, was observed in the Lake States in 1935, and subsequently in Maryland, Wisconsin, and Massachusetts; and also on ponderosa pine in the Northwest. The cause is not yet known, but it may be some abnormal physiological condition such as rapid needle growth, which preceded the 1935 injury. Frost appears to be a factor in some cases.

Dearness, John. 1928. **New and noteworthy fungi.** Mycologia 20: 235-246.

Among the new species listed are the following on eastern white pine: *Hendersonula pinicola* in North Carolina; *Leptothyrium stenosporum* in Georgia.

Delaware State Forestry Department. 1953. **A foliage disease of white pine seedlings.** Del. State Forestry Dept. Rpt. (1952-53), 21 pp.

Cylindrocladium scoparium, usually a saprophyte, has caused much damage to the foliage of white pine seedlings in the nursery. Manzate, Fermate, and Bordeaux mixture all gave satisfactory control without injuring the foliage. Mercurial compounds injure foliage and have been rejected.

Deuber, C. G. 1931. **White pine blight.** Natl. Shade Tree Conf. Proc. 7: 97-100.

Stunted white pines with short, yellow-green needles have been observed throughout southern New England. Swampy ground and dry hillsides seem to be the most common locations for them but wherever they are found they are intermingled with normal trees. Histological studies have shown that cells as well as size of needles are dwarfed. Microchemical tests showed deficiencies of iron and starch in diseased trees. Differences in root development were also found. No causative organism or condition has been isolated; the poor growth results from unfavorable environmental factors and unexplained physiological conditions.

Doolittle, Warren T. 1948. **White pine blight in relation to site and thinning.** Jour. Forestry 46: 928-929.

Fifty-year-old eastern white pine plantations at Biltmore, N. C., have exhibited white pine blight for 3 years. On dry sites, 18.6% of the pines were infected compared to 5.2% on moist sites. Growth rate of diseased trees was at least 33% less than that of normal trees, but there was no apparent difference in growth rate of diseased trees according to site or thinning treatment.

Faull, J. H. 1922. **Some problems of forest pathology in Ontario—needle blight of white pine.** Jour. Forestry 20: 67-70.

The distribution and symptoms of needle blight are discussed and the study of sample trees is described. Based on 4 years' observations it is concluded that young stands are not likely to be seriously depleted by needle blight, but that injury to heavily blighted mature stands may be so great as to be a deciding factor in determining the time of harvesting. In regions subjected to sulfur fumes, it is possible to differentiate between blight and sulfur-fume injury if the examination is made at the right time.

Faull, J. H. 1929. **A fungus disease of conifers related to the snow cover.** Jour. Arnold Arboretum 10 (1): 3-8.

The Phacidium blight is caused by a fungus very similar to, if not identical with, *P. infestans*. It is highly infectious and may have a rapid spread, causing browning and fall of white pine needles during the first summer. It appears most virulent on white spruce but attacks a number of native conifers. Control in the nursery with a dormant lime-sulfur spray applied in the fall is cheap and easy.

Fink, Bruce. 1911. **Injury to *Pinus strobus* caused by *Cenangium abietis*.** Phytopath. 1: 180-183, illus.

The type of injury, location of injured trees, and appearance of this Ascomycete on some white pines in Ohio is described. The disease appears to strike only occasionally and usually after drought years. Trees on high ground seem to be more often affected than those on somewhat lower ground.

Gifford, C. M. 1911. **Damping-off of coniferous seedlings.** Vt. Agr. Expt. Sta. Bul. 157, 171 pp., illus.

A species of *Fusarium* was isolated from 2-year-old white pine seedlings. This fungus may cause damping-off and root rot. It sometimes kills older seedlings by attacking roots and stems. Nursery beds may be disinfected with a 0.5 to 1% solution of formalin applied at the rate of ¾ gallon per square foot. It should be applied at least a week before the seed is to be sown.

Haddow, W. R. 1933. **Disease as a factor in transition of pine to stable types.** Forestry Chron. 9: 30-35.

Most pines that die, die of diseases. The root- and butt-rotting fungi, while of comparatively little importance as wood destroyers, are the first to cause the breaking up of the stand; and they continue to operate, accounting in the end for the destruction of most of the trees. There is an explainable relationship between the incidence of brown butt rot and site. Other rots are described.

Haddow, W. R. 1934. **An instance of early infection of white pine (*Pinus strobus* L.), by *Trametes pini*.** Forestry Chron. 10: 199-202.

Although heart-rots are generally regarded as diseases of mature or overmature trees, there is evidence that young trees may become infected. One such tree, 52 years old when discovered, suffered a broken top when 11 years old and became infected when 16 to 19 years old.

Haddow, W. R. 1938. **The disease caused by *Trametis pini* (Thore) Fries in white pine (*Pinus strobus* L.).** Royal Canad. Inst. Trans. 22: 21-80.

The disease is non-lethal yet very destructive. It is of widespread distribution. Normally it causes heart rot in the middle portion of the trunk, and is often responsible for decay in old trees. Detection is possible mainly through the occurrence of punk knots and associated symptoms. Several proposals for control are reviewed critically and the pathological rotation is discussed.

Hahn, Glen G., Carl Hartley, and Arthur S. Rhoads. 1920. **Hypertrophied lenticels on the roots of conifers and their relation to moisture and aeration.** Jour. Agr. Res. 20: 253-266, illus.

This condition was observed first on ponderosa pine, but has since been found on many pines, including pitch pine and eastern white pine. It appears to be associated with excessive soil moisture (or deficient soil aeration). The symptoms are decreased by top pruning and increased by root injury.

Hedgcock, George G. 1932. **Notes on the distribution of some fungi associated with diseases of conifers.** U.S. Dept. Agr. Plant Dis. Rptr. 16: 28-42.

These diseases are reported as associated with white pine: *Aposphaeria pinea, Asterina pinastri, Caliciopsis pinea, Chilonectria cucurbitula, Coccomyces pini, Cytospora pinastri, Hendersonula pinicola, Hypoderma brachysporum, Leptothyrium stenosporum, Lophodermium pinastri, Mollisia pinastri, Mollisia pinicola, Nectria* sp., *Nectria cinnabarina, Neopeckia coulteri, Ophionectria scolecospora, Pestalozzia funerea, Pestalozzia peregrina, Pezizella minuta, Phacidium planum, Phoma strobiligena, Sclerophoma pini, Septoria spadicea, Sphaeropsis ellisii, Valsa abietis, Valsa kunzei, Valsa pini,* and *Hypoderma lineare.*

Heiberg, Svend O., and Donald P. White. 1951. **Potassium deficiency of reforested pine and spruce stands in northern New York.** Soil Sci. Soc. Amer. Proc. 15: 369-376, illus.

Symptoms of the deficiency are general chlorosis followed by browning and dying of needles, decreased height and diameter growth, shortening of the needles and of their period of persistence. Application of potash at the rate of 200 pounds per acre increased annual height growth 46 to 104% and the effect continued at least 6 years.

Heiberg, S. O., E. L. Stone, and D. P. White. (1954?). **Potash and magnesium fertilization of young pine and spruce trees.** N.Y. State Univ. Col. Forestry and Col. Agr. 8 pp., illus.

Plantations on old fields or burns in and around the Adirondacks commonly have symptoms of nutrient deficiency. Lack of potassium results in sparse foliage or a yellow-green to yellow, or even brownish, color. Height and needle growth may be greatly reduced. Lack of magnesium shows up as a conspicuous yellowing of the needle tips. Symptoms appear in the fall and are most pronounced in early spring. Fertilizers to overcome deficiencies are listed, along with various methods of application.

Hepting, George H., and Albert A. Downs. 1944. **Root and butt rot in planted white pine at Biltmore, North Carolina.** Jour. Forestry 42: 119-123.

A high percentage of the trees (75%) in previously thinned white pine lots had root and butt rots. A smaller perceintage of those in the isolation strips around these plots were rotted, and a very much smaller part (4%) of the trees in previously unthinned plots were butt-rotted. Most of the rots were caused by *Fomes annosus,* some by *Polyporus circinatus* and *P. schweinitzii.*

Hirt, Ray R. 1959. ***Pinus strobus* L. A literature review and discussion of its fungus diseases in North America.** N.Y. State Univ. Col. Forestry Tech. Pub. 82, 90 pp. Syracuse.

Assembles the more important American references to the fungus diseases of *Pinus strobus* in North America. Provides an abstract for each reference to white pine disease, and includes personal comments on some of the more common diseases.

Hubert, Ernest E. 1935. **A disease of conifers caused by *Stereum sanguinolentum.*** Jour. Forestry 33: 485-489, illus.

The disease (commonly called the mottled bark disease) is described on white pine and a number of other conifers in plantations in Idaho. The damage appears to have been aggravated by drought conditions for several years. External characteristics of the disease are few and inconspicuous; it is suggested that pruning cuts be made close to the trunk so that the wounds will heal quickly as possible.

Ibberson, J. E., and H. Streater. 1952. **White pine blight responds to fertilizer applications.** Pa. Dept. Forests and Waters 4 (2): 30-31, 46.

Reports on an experiment in Cook Forest, Pennsylvania, to test the response of diseased trees to various fertilizer treatments. The disease appeared to respond definitely and rapidly to certain applications of complete fertilizer (10-6-4). But none of the applications of trace elements gave positive results.

Nemec, A. 1942. **Zur Kenntnis der Kali- und Magnesia-Mangelerscheinungen bei Samlingen und Kulturen der Kiefer.** Forstwiss. Centbl. 64: 160-166.

In several localities in Czechoslovakia where the soil was deficient in potassium or in both potassium and magnesium, a yellowing of the needle ends in some Scotch pine and white pine seedlings was observed. Compared with unaffected plants growing in the same locality, those that were affected showed a lower potassium and magnesium content and a higher magnanese content in their needles, and sometimes in both needles and stem.

New Hampshire Forestry Commission. 1908. **The pine blight of 1907 and 1908.** N.H. Forest Comn. Bien. Rpt. 1907-1908: 7-15.

An account of the widespread occurrence of white pine needle blight in northern New England during 1907, and to a lesser degree during 1908. The yellowing of the needles was attributed to either a *Septoria* species or to winter root damage. A twig blight occurred in 1908 that was caused by *Pineus pinifoliae.*

Nobles, Mildred K. 1953. **Studies in wood-inhabiting hymenomycetes. I. *Odontia bicolor*.** Canad. Jour. Bot. 31: 745-749, illus.

Cultural methods have shown that *Odontia bicolor* is the cause of an important butt rot in white pine and other species in Canada. It is confined to the heartwood. In the incipient stages it is described as a pink to reddish-brown discoloration, while in the advanced stage it is a white pitted, stringy, or feather rot.

Owens, C. E. 1936. **Studies on the wood-rotting fungus *Fomes pini*. II. Cultural characteristics.** Amer. Jour. Bot. 23: 235-254, illus.

Agar cultures from 6 genera and 19 species could be placed into 3 groups according to their growth and development. The isolate from white pine occurred in the majority group characterized by rapid growth rate, producing a thick, fluffy, buff-colored mycelial mat.

Percival, W. Clement. 1933. **A contribution to the biology of *Fomes pini* (Thore) Lloyd (*Trametes pini* (Thore) Fries).** N.Y. State Col. Forestry Tech. Pub. 40, 72 pp., illus.

White pine is one of 59 species listed as hosts of *Fomes pini*. This report includes a history of the disease and its distribution, occurrence, and sporulation. Various culture experiments are reported. Among them red spruce was successfully inoculated with cultures from white pine; and white pine was one of five species successfully inoculated with a single culture from western white pine.

Ray, W. W. 1936. **Pathogenicity and cultural experiments with *Caliciopsis pinea*.** Mycologia 28: 201-208, illus.

Artificial inoculation experiments demonstrated that *C. pinea* is pathogenic and produces cankers on the trunks and branches of white pine. In pure culture experiments, spermagonia and mature stromatic columns containing asci and spores were developed.

Schantz-Hansen, T., W. H. Kenety, G. H. Wiggin, and E. C. Stakman. 1923. **A study of the damping-off disease of coniferous seedlings.** Minn. Agr. Expt. Sta. Tech. Bul. 15, 35 pp., illus.

Report on an extensive study of nursery practices that affect seedling germination and fungi that cause damping-off of white, red, and jack pines. Factors tested and discussed are time of sowing, seed covering, manuring, shading, watering, mulching, density of stocking, drainage, soil texture, seedbed sterilization, and use of fungicides. When recommended practices were followed with white pine, germination increased and damping-off decreased.

Sleeth, Bailey. 1938. **Pruning wounds as an avenue of entrance for *Stereum sanguinolentum* in northern white pine plantations.** U.S. Forest Serv. Allegheny Forest Expt. Sta. Tech. Note 22, 3 pp.

A reconnaissance was made of white pine plantations in Pennsylvania to determine the prevalence of sporophores on old pruning wounds. In general, the percentage of wounds bearing sporophores was greater among large wounds. Care should be taken in pruning dead branches to prevent injury to the live wood. Young pruned trees in which fungus is established are considered worthless long before they reach merchantable size.

Snell, Walter H. 1929. ***Dasyscypha agassizii* on *Pinus strobus*.** Mycologia 21: 235-242, illus.

Dasyscypha agassizii was very abundant on planted white pine in New York, especially on blister rust cankers. This fungus had been reported only on *Abies balsamea,* but collections are here noted from *Tsuga canadensis, Pinus monticola, Picea rubra, P. mariana,* and possibly *Pseudotsuga taxifolia.* The habitat of *D. agassizii* is apparently subboreal.

Spaulding, Perley. 1929. **Decay of slash of northern white pine in southern New England.** U.S. Dept. Agr. Tech. Bul. 132, 20 pp.

White pine slash rots about as follows: fruiting bodies of fungi, especially *Lenzites sepiaria* and *Polystictus abietinus,* begin to form in the 2nd year after cutting and cause most of the decay, which is well advanced by the 4th year. At about the 8th year the slash piles flatten to ground and by the 15th year most slash is well rotted. By the 20th year the material has formed a mat of fibrous mold under the litter.

Spaulding, Perley, and J. R. Hansbrough. 1943. **The needle blight of eastern white pine.** U.S. Bur. Plant Indus. Div. Forest Path. Mimeo., 2 pp.

The blight usually appears after prolonged periods of moist, cloudy weather which are followed by hot, dry days. It is more apt to occur when the needles are most tender and succulent. It is a symptom of inadequate moisture supply to the needles, probably because of a deficiency of active feeding rootlets. The condition is seldom fatal but recovery can be helped by mulching, fertilization in the dormant season, and crown pruning.

Spaulding, Perley, H. J. MacAloney, and A. C. Cline. 1935. ***Stereum sanguinolentum* a dangerous fungus in pruning wounds on northern white pine.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 19, 2 pp.

To avoid serious damage from attacks by this fungus, prune before branches exceed 2 inches in diameter. The exposed heartwood of larger branches was not well covered with protective pitch and so provided a favorable entrance for this fungus.

Stambaugh, W. J. 1952. **A study of the needle cast diseases of conifers in Pennsylvania.** Jour. Forestry 50: 944.

Four needle-cast fungi of Pines are common in Pennsylvania: *Bifusella linearis* and *Hypoderm desmazierii* are mildly parasitic on white pine; *Lophodermium pinastri* is a widespread saprophyte on all pine needles; and *Hypoderma lethale* is the most virulent but is confined to native hard pines. Needle-cast epidemics were found to be closely related to periods of high humidity. Trees of poor vigor are the usual victims.

Stone, Earl L., Jr. 1953. **Magnesium deficiency of some northeastern pines.** Soil Sci. Soc. Amer. Proc. 17: 297-300.

Magnesium deficiency of white, red, and jack pines on light-textured soils south and west of the Adirondacks caused a bright yellow coloration in the needle tips of the current year's growth. This symptom appeared in the fall. Only in extreme deficiency or where magnesium and potassium deficiency were combined did large reductions in shoot and needle growth occur. In such cases, fertilization gave statistically significant increases in height growth.

Strong, F. C. 1941. **Root and butt rot in the pinetum at Michigan State College.** Mich. Agr. Expt. Sta. Quart. Bul. 23: 159-163.

A dozen trees in a 44-year-old white pine plantation were windthrown by a gale. All of them had trunk or roots weakened by *Polyporus schweinitzii,* which was shown to have spread from an infected tree to adjacent ones. Thinning or fertilizing the stand to increase vigor should help contain the disease, but no economical way to eradicate it is known.

Swingle, Roger U. 1944. **Chlorotic dwarf of eastern white pine.** U.S. Dept. Agr. Plant Dis. Rptr. 28: 824-825.

This disease (common in 2- to 15-year old plantations throughout Ohio) is characterized by stunted roots, top, and foliage. The foliage is greenish-yellow to yellow, and second-year needles fall prematurely. No causal organisms or weather patterns are consistently associated with the disease.

Toole, E. Richard. 1949. **White pine blight in the Southeast.** Jour. Forestry 47: 378-382.

Reports increase of white pine blight in the Southeast. Needle dieback is accompanied by reduced growth rate and there may be appreciable mortality. Some of the possible causes of this disease are discussed. Needle fungi have been eliminated as a likely factor. Further work is needed to determine the significance of root fungi and root aphids, the latter either as a primary cause or as vectors of a virus.

Toumey, J. W., and T. T. Li. 1924. **Nursery investigations with special reference to damping-off.** Yale Univ. School Forestry Bul. 10, 36 pp.

Sulfuric acid applied at the rate of 3/32 fluid ounces per square foot of seedbed effectively controlled damping-off, gave higher survival of white pine, white spruce, and hemlock than heavier dosages—and greatly reduced weed growth. The acid delayed germination, reduced germination percent, and reduced top and root growth in porportion to the amount used. Formalin was not satisfactory for treating seedbeds. The tests were made during one season at New Haven.

Vermillion, M. T. 1950. **A needle blight of pine.** Lloydia 13: 196-197.

Provisional descripion of a disease of white pine seedlings, characterized by considerable browning and killing of needles. The disease seems to be the white pine needle blight caused by a species of *Pestalozzia,* probably *P. funerea.*

Walker, E. A. 1946. **Eastern white pine affected with needle blight in Maryland.** U.S. Dept. Agr. Plant Dis. Rptr. 30: 320.

Needle blight appeared in Maryland in July 1946 at several locations in Montgomery, Frederick, Carroll, and Prince George's Counties. The conditions under which it developed verify the statements by Spaulding and Hansbrough (1943).

Waterman, Alma M. 1943. ***Diplodia pinea* and *Sphaeropsis malorum* on soft pines.** Phytopath. 33: 828-831.

Observations and inoculation tests indicate that neither fungus is parasitic upon new leaves and twigs of young, vigorously growing white pine. Both fungi occasionally contribute to the unhealthy condition of soft pines weakened by other agents. Improved growing conditions and the protection and prevention of wounds will lessen the possibility of infection.

Wean, Robert E. 1937. **The parasitism of *Polyporus schweinitzii* on seedling *Pinus strobus*.** Phytopath. 27: 1124-1142, illus.

Sand culture experiments involving five nutritional conditions showed that phosphorus-deficient 1- and 2-year-old seedling white pines were highly susceptible to attack. Roots in nutrient solutions with pH 6 and 7 were also severely attacked. The fungus is a direct parasite capable of penetrating directly through living cortical cells of the roots. Parasitism of seedling roots indicates that this fungus can be spread by nursery stock.

White, L. T. 1953. **Studies in forest pathology X. Decay of white pine in the Timagami Lake and Ottawa Valley areas.** Canad. Jour. Bot. 31: 175-200, illus.

The study of decay and decay relationships of 1,012 white pine trees in ten 1-acre plots located in pure even-aged stands showed that 52% contained decay. A well-defined relationship existed between age and decay. The proportion of trees with decay increased gradually with age from 40% in the 60-year age class to 100% in the 220-year age class. The loss in merchantable volume increased from 4% at 60 years to 40% at 200 years.

Wycoff, H. B. 1952. **Methyl bromide controls soil organisms which cause mortality of eastern white pine seedlings.** U.S. Forest Serv. Tree Planters Notes 12: 11-14.

Soil sterilization with methyl bromide before sowing white pine seed on green-manured plots gave satisfactory control of damping-off.

York, H. H. 1932. **New disease on white and red pine.** Jour. Forestry 30: 505-506.

A new disease, apparently caused by a fungus, has been discovered in red and white pine plantations in the vicinity of Rochester, N. Y. The symptoms include a profuse exudation of resin at the base of the trunk, permeating the soil for several inches around each diseased tree. Examination of the infected parts (roots and lower trunk) reveal characteristic mottling and an enlargement and breakdown of resin pores. The disease apparently requires 3 to 5 years to kill a tree.

York, Harlan H. 1943. **Detecting pathological regions and nonconducting tissues in living pine trees by means of dyes.** (Abs.) Phytopath. 33: 20.

White, red, and Scotch pine were cut off near the ground and their butts placed in aqueous solutions of dyes for 36 to 72 hours. Certain dyes penetrated the trees to the needle tips. Regions of the stem where the dyes failed to penetrate were found to be infected with fungi and bacteria. Such lesions were more abundant in weak trees than in vigorous trees.

Barnes, T. Cunliffe. 1929. **An enquiry concerning the natural history of the white pine weevil (*Pissodes strobi*).** 4th Internatl. Congress Ent. Trans. 2: 412-413.

Oviposition is not possible until the spring after emergence when the ovarian tubes are large, flexed, and contain a prominent vitelarium. The spermary of the young males is advanced, but the glands do not mature until spring. Weevils leave the pine litter under trees when the mean temperature rises to 60° F. and fly readily if the day temperature rises above 70° F. Aestivation occurs in July at a mean temperature of 70° F.

Blackman, M. W. 1919. **Report on the white pine weevil.** Maine Forestry Dept., 12 pp.

Presents a general description of the insect, its life history, choice of food plants, method of attack, damage. Advises cutting and burning leaders for control, or better, Hopkins' disposition of cut leaders supplemented by systematic collection of adult beetles in spring and early summer. Comments on why virgin forests were free of weevil injury and suggests planting methods that might produce the same result.

Crosby, David. 1950. **Concentrated lead arsenate spray for control of white pine weevil.** Jour. Forestry 48: 334-336.

Reports results of a spray program for the control of white-pine weevil through the use of concentrated lead arsenate applied with a knapsack sprayer. This spray was applied to the leaders in the spring before the weevils became active. Percentage of weeviling for each year is given for a 5- to 7-year period after treatments. One treatment gave adequate protection for 4 years. Two well-timed treatments spaced 4 years apart should give a high degree of protection for 8 years. This period of protection should permit a high percentage of well-formed butt logs.

Crosby, David. 1954. **How to control the white pine weevil with a hand sprayer.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Res. Note 30, 3 pp.

Describes the types and preparation of materials and equipment needed to control weevil with lead arsenate. Spraying can be done in late winter or spring, but in Connecticut it should be completed by the end of April. The first treatment should be made when 2 to 5% of the trees are weeviled in 1 year and should be repeated when weeviling builds up to 10% annually. Seldom should more than two treatments be required to produce straight 16-foot butt logs.

Doolittle, Warren T. 1954. **Weevils attracted to bud-pruned white pine.** U.S. Forest Serv. Southeast. Forest Expt. Sta. Res. Note 63, 2 pp.

Alternate rows were bud-pruned in a white pine plantation beginning when it was 5 years old. Although pruned and unpruned trees were approximately the same height after 4 years of pruning, the bud-pruned trees had a significantly higher incidence of weevil attack. Bud-pruning white pine is not recommended.

Graham, S. A. 1918. **The white pine weevil and its relation to second-growth white pine.** Jour. Forestry 16: 192-202, illus.

Describes the life history of the weevil, the type of injury it causes, and its distribution by regions. The author studied the age class, stand density, and rate of growth of the white pines attacked. He found: (1) the upturned laterals were about one-third shorter than the weeviled terminals they replaced but that the differences became less as the leader lengths increased; (2) that fewer trees were weeviled as stand density increased; (3) that loss in average total height per tree and percentage of unmerchantable trees decreased with increasing stand density. Suggests control measures.

Graham, S. A. 1926. **Biology and control of the white-pine weevil, *Pissodes strobi* Peck.** N.Y. Agr. Expt. Sta. Bul. 449, 32 pp., illus. (Cornell.)

The biology of the insect and the direct and indirect methods of control are discussed. Experiments in New York and Minnesota indicate that young white pine need no longer to be seriously menaced by the white-pine weevil. The insect can be controlled under any condition in which a fully stocked (1,500 trees per acre) stand can be maintained the first 25 or 30 years of the rotation, or where white pine can be grown under the shelterwood system or some other system that will provide shade for the sapling pines.

Holdsworth, Robert P. 1943. **Some work on the white pine weevil.** Jour. Forestry 41: 143-144.

Since 1920 weevilled white pine tips have been removed annually from some 141 acres of white pine type on the Mt. Toby Forest in Massachusetts. Since 1936 the weevilled trees have been shaped by removing all except the best lateral at the base of the weevilled tip. This practice has reduced stem crook to a negligible amount. Number of tips collected each year declined from 1,400 in 1920 to only 26 in 1942.

Hopkins, A. D. 1907. **The white pine weevil.** U.S. Bur. Ent. Circ. 90, 8 pp., illus.

The insect, its life history, the species and kind of trees it attacks, and the type of damage done are described and illustrated. Recommends control by cutting off infested leaders in July. They should be kept in screened containers in the area for a year so that weevil parasites may escape. Treatment should be repeated at least 3 years in succession.

Kriebel, Howard B. 1954. **Bark thickness as a factor in resistance to white pine weevil injury.** Jour. Forestry 52: 842-845, illus.

Susceptibility of white pine to injury by the weevil is partly correlated with bark thickness at breast height. Among dominant trees of equal diameter in even-aged stands, trees with thin bark are weevilled less frequently than trees with thick bark. A significant proportion of the unweevilled trees are below average in bark thickness.

Littlefield, E. W. 1942. **White pine weevil damage reduced by close spacing.** New York State Conserv. Dept. Forest Invest. Notes 37, 1 pp.

Of two small plantations of white pine on loam soils, the one with an original spacing of about 3.5 x 3.5 feet showed 76% of the trees to have been weevilled in some degree and 79% of the weevilled trees to have made good recovery; in the one with a spacing of 6 x 6 feet, 96% of the trees were weevilled and only 4% of these showed good recovery.

MacAloney, Harvey J. 1930. **The white pine weevil (*Pissodes strobi* Peck)—its biology and control.** N.Y. State Col. Forestry Tech. Pub. 28, 87 pp., illus.

A comprehensive report on the weevil, including a description of damage to the host, historical notes, life history, and methods of control. Based on a study made from 1923 to 1928.

MacAloney, Harvey J. 1943. **The white pine weevil.** U.S. Dept. Agr. Cir. 221, 30 pp., illus.

Gives the life cycle of the weevil *(Pissodes strobi,* Peck). Insect population levels are partially controlled by age, height, and vigor of the trees; soil conditions; exposure; climatic factors; predacious animals, birds, and insects; amount of natural food; and stand composition. The only feasible control is to grow the host species in dense pure stands or in mixture with the better hardwoods. Many species are attacked; but white pine, Norway spruce, and jack pine (in that order) are favored.

Maughan, W. 1930. **Control of the white pine weevil on the Eli Whitney Forest.** Yale Univ. School Forestry Bul. 29, 37 pp., illus.

Weevilled tips should be removed before emergence of the weevil, beginning the first year of infestation and continuing each year until the crowns have closed, usually between 12 to 14 years of age. This reduces infestation and results in more acceptable stems per acre. On poor sites even this practice will not bring through enough acceptable stems. Cost data included.

Mott, Paul B. 1930. **An annotated bibliography of the white pine weevil, *Pissodes strobi* (Peck), for white pine blister rust workers and others.** N.J. Dept. Agr. Cir. 177, 37 pp.

Chronologically arranged, the references date from 1817, when Peck originally described the insect, to 1930, when MacAloney and Taylor published their treatments of the insect. The following articles are recommended: Hopkins 1907; Blackman and Ellis 1916; Davis 1920; Peirson 1922 and 1928; Graham 1918 and 1926; MacAloney 1926, 1929, and 1930; Barnes 1928 and 1929; Plummer and Pillsbury 1929; and Taylor 1929 and 1930.

Peirson, H. B. 1922. **Control of the white pine weevil by forest management.** Harvard Forest Bul. 5, 42 pp., illus.

Discusses the history, biology, damage, and control of this native pest by forest management and other measures. Dense stocking of young white pine limits forking after weevil attack; rapidly grown trees are less damaged than slow grown; mixtures of hardwoods in stand protect pines; native predators and parasites, sprays, and removal of infested leaders assist in control.

Plummer, C. C., and A. E. Pillsbury. 1929. **The white pine weevil in New Hampshire.** N.H. Agr. Expt. Sta. Bul. 247, 32 pp., illus.

Integrates the results of various original experiments and observations on the life history and habits of the white-pine weevil. The damage it inflicts on pine and methods of control, both direct and indirect, are also discussed.

Potts, S. F., A. C. Cline, and H. L. McIntyre. 1942. **The white pine weevil and its control by the application of concentrated sprays.** Jour. Forestry 40: 405-410, illus.

The application of concentrated spray to 65 acres of white pine plantations 8 to 13 years of age gave excellent protection against the white-pine weevil. An effective mixture was (by weight): lead arsenate, 1 part; water, 10 parts; adhesive oil, 0.3 part — with or without 0.02 part of spreader. About 5 gallons of mixture per acre is applied to the leaders late in March or during April wtih a compressed air sprayer. The sprayer and accessory equipment are described.

Schenefelt, Roy D. 1951. **A further note on the control of the white pine weevil.** Jour. Forestry 49: 575-576.

A block of some 41,000 white pine trees was ground-sprayed with lead arsenate and other insecticides. Three years after spraying, only 0.5% of the leaders were infested and there appeared to be little need for another spraying. Recommends that lead arsenate be used in ground spraying because it is easy to see, remains for as long as 5 months on the leaders, does not have a contact action on the parasites, and is safer to use. Some observations on weevil epidemiology.

Steiner, G. 1930. ***Neodiplogaster pinicola* n. sp., a nema associated with the white pine weevil in terminal shoots of the white pine.** Jour. Agr. Res. 41: 125-130.

A new nema is described. It may be of economic importance as an enemy of the white-pine weevil for it probably preys on the eggs and larvae.

Taylor, Raymond L. 1928. **The arthropod fauna of coniferous leaders weeviled by *Pissodes strobi* (Peck).** Psyche 35: 217-225.

In a study of the bionomics of the white-pine weevil, the author bred 16 species of Arachnida and 79 of Insecta from weeviled white pine leaders. Many of them apparently have no definite relationship with the weevil. An annotated list is given, eliminating species known to be parasites or predators. Many of the species listed are not pine feeders; they used the weevil burrows only as places to hibernate.

Taylor, Raymond L. 1929-30. **The biology of the white pine weevil, *Pissodes strobi* (Peck), and a study of its insect parasites from an economic viewpoint.** Ent. Amer. 9: 167-246; 10: 1-86, illus.

A comprehensive review of previous work and new studies on the white-pine weevil, with particular reference to population dispersion, numbers, survival, and parasitism. The primary and secondary parasites, which destroy about 16% of the mature weevil larvae, are discussed in detail. Possibilities of control by native or introduced parasites are poor but should be explored.

Taylor, Raymond L. 1930. **The natural control of forest insects. I. The white pine weevil, *Pissodes strobi* Peck.** Jour. Forestry 28: 546-551.

Using material from a more complete report (Taylor 1929-30), the author summarizes factors acting in the natural control of the white-pine weevil according to stages in the insect's development. Tables show the effectiveness of birds and the computed effectiveness of parasites.

West, A. S. 1947. **The effect of the white pine weevil on plantations on the University of New Brunswick forest.** Forestry Chron. 23: 291-296.

Presents tabulations of annual weevilling (1932-45) of four plots in plantations totaling about 2 acres. Shows frequency of weevilling, average height and diameter growth, frequency of forked trees, mortality by periods, and incidence of blister rust. The plots were subjected to many adverse conditions, but the very poor condition of these plots is largely the result of weevilling and blister rust.

Other Insects

Anonymous. 1945. **Insect control: pests of pines.** Amer. Nurseryman 81 (10): 22-23.

Gives formulas and spraying instructions for chemical control of pine-leaf scale *(Chionaspis pinifoliae)*, pine bark aphis *(Pineus strobi)*, and pine sawflies *(Neodiprion lecontei* and *N. abbotti)*.

Atwood, C. E., and O. Peck. 1943. **Some native sawflies of the genus *Neodiprion* attacking pines in eastern Canada.** Canad. Jour. Res. Sec. D: 109-144, illus.

In eastern Canada, sawflies of at least 12 species of the genus *Neodiprion* have been causing damage to white, red, and jack pine by eating the needles. Keys are given for identifying adult females of 11 species and larvae of 10 species. Two of the species are described as new. The sawflies can be distinguished by their habits, notably oviposition, feeding, and overwintering.

Baker, W. L. 1941. **Effect of gypsy moth defoliation on certain forest trees.** Jour. Forestry 39: 1017-1022.

Injury by the gypsy moth in New England has been most severe to oaks and white pine during the period 1912-21 when records were made of defoliation, mortality, and loss of diameter increment. Percentage of defoliation and mortality were roughly equivalent — about 30% for highly favored food trees and about 10% for those unfavored. Greatest mortality occurred before 1915 among trees weakened by heavy defoliation, drought, and *Agrilus bilineatus* activity.

Baker, W. L., and A. C. Cline. 1935. **A study of the gypsy moth in the town of Petersham, Mass., in 1935.** Jour. Forestry 34: 759-765.

Feeding preferences of the gypsy moth larvae is the key to control of the insect. Oaks, poplar, gray birch, alder, willow, and apple are highly favored food sources for larvae of all ages; but white pine is favored by later instars, and maple will be fed upon in these later stages. Specific protection recommendations are made for a variety of stand conditions. Protection of coniferous plantations by weeding and clearing of isolation strips should be given first preference in any silvicultural control program.

Balch, R. E., and G. R. Underwood. 1950. **The life-history of *Pineus pinifoliae* (Fitch) and its effect on white pine.** Canad. Ent. 82(6): 117-123.

A detailed life-history of *Pineus pinifoliae.* Unusual abundance of the insect was first noted in 1942 in New Brunswick. Spruce is little affected, but drooping of affected shoots of white pine results in some crookedness at the nodes and reduced growth. In sample-plot experiments, white pine mortality was slight and was confined to small trees, but loss of growth was considerable and tended to favor competition by spruce and red pine.

Baldwin, H. I. 1948. **Pales weevil damage after fire and logging.** N.H. Forestry and Recreation Comn. Fox Forest Notes 37, 1 p.

Of more than 1,000 seedlings tallied, 12% had been killed and an additional 35% severely injured by the Pales weevil in the first season after logging. White and Norway pine planted the spring after logging suffered even heavier losses — 60 to 70% were killed and an additional 20 to 30% injured. Trees planted the spring after fire showed a loss of 30% if the burned timber had been salvaged and 13% where the timber was not salvaged. Four-year-old stock was damaged least.

Baldwin, H. I. 1953. **Prevention of bark beetle attack in conifers.** N.H. Forestry and Recreation Comn. Fox Forest Notes 51, 2 pp.

Most bark beetles attack only dead and dying trees, slash, stumps, green logs, and lumber. Prevention can be accomplished by keeping the trees in vigorous growing condition, using sanitation to prevent accumulation of breeding material, and spraying uninfested trees or products with benzene hexachloride.

Bess, Henry A., Stephen H. Spurr, and E. W. Littlefield. 1947. **Forest site conditions and the gypsy moth.** Harvard Forest Bul. 22, 56 pp.

Resistant stands occur more commonly on soils that have an adequate supply of moisture and organic matter, and are characterized by full stocking and relatively vigorous growth. They are also found on the poorer sites where there has been a minimum of disturbance. White pine types are listed as resistant to gypsy moth — not likely to be defoliated unless badly abused or surrounded by susceptible types.

Carter, E. E. 1916. ***Hylobius pales* as a factor in the reproduction of conifers in New England.** Soc. Amer. Foresters Proc. 11: 297-307.

In New England, white pine reproduction has seldom been obtained promptly after the removal of the same species; this has been generally attributed to the competition of hardwoods. But careful investigations have shown that the Pales weevil kills large quantities of young seedlings. Therefore, cutover lands should not be planted until the third and preferably the fourth season after logging. The injury done by this weevil is an added argument against the use of shelterwood or strip methods in the reproduction of white pine.

Craighead, F. C. 1950. **Insect enemies of Eastern forests.** U.S. Dept. Agr. Misc. Pub. 657, 679 pp., illus.

About 40 different insects are listed as attacking white pine, although most of them are of minor economic importance to white pine. These insects are described, together with a description of the damage they cause. Critical points in the life history are discussed and control measures are described briefly.

DeGryse, J. J. 1943. **Note on *Marmara fasciella* Chambers.** Canad. Ent. 75: 40.

Marmara fasciella Chamb. has been found to construct long linear mines in the phloem of the trunk and branches of white pine and is probably distributed over the entire species range. The adults emerge in late May and early July and oviposit on the bark. The larva penetrates into the phloem through the underside of the egg, constructs about half of the mine during late summer and autumn and hibernates there; it resumes feeding early in the spring, completes its mines in May or June, and then spins its cocoon. Parasites noted.

Dingler, Max. 1928. **Chalcographus-frass in Weymouthskiefern.** Forstwiss. Centbl. 50: 357-360, illus.

The bark beetle *Pityogenes chalcographus,* a common enemy of *Picea excelsa,* also attacks white pine planted in mixture with spruce.

Dumbleton, L. J. 1932. **Report on spruce aphis investigation.** New Zeal. Jour. Sci. and Technol. 13: 207-220.

The biology of *Neomyzaphis abietina* Walker on spruce in New Zealand was studied. Data are given on the seasonal variation in numbers of aphis on spruce, the length of the developmental stages, and the reproductive capacity. No sexual forms were noted and no alternate hosts found. Laboratory experiments showed that the alates can reproduce on white pine, and in one case white pine was successfully infested with apterous aphids.

Easterling, George Riley. 1934. **A study of the insect fauna of a coniferous reforestation area in southeastern Ohio.** Ohio Jour. Sci. 34: 129-146, illus.

A survey of densely spaced conifer plantations, aged 2 to 24 years and containing 12 species, showed that an association of insects typical of coniferous forest had been established. The most serious pests were white pine aphid *(Adelges pinicorticis)* and pine leaf scale *(Chionaspis pinifoliae),* which attacked the older white pines.

Friend, R. B., and H. H. Chamberlin. 1942. **Some observations on Pales weevil injury to white pine plantings in New England.** Conn. Agr. Expt. Sta. Bul. 461: 530-537.

Small plot studies of Pales weevil behavior at Keene, N. H., indicate that, in continuously logged regions, pine may be planted the second spring after logging rather than the third spring if as much as 15% weevil damage is acceptable. In regions where there has been little commercial pine logging, such as around New Haven, Conn., weevil population is low and pine may be planted the first spring after logging with little or no risk of damage.

Graham, Samuel A. 1935. **The spruce budworm on Michigan pine.** Mich. Univ. School Forestry Bul. 6, 56 pp., illus.

White pine is seldom severely attacked by the spruce budworm.

Heinrich, Carl. 1931. **A new pine moth from Connecticut.** Wash. Ent. Soc. Proc. 33: 196-197.

Eucosma gloriola breeds in tips of twigs of white pine; descriptions of larva and adults are given.

Henry, H. K. 1942. **Injury to pines by a leaf-chafer.** N.Y. State Conserv. Dept. Forest Invest. Notes 41, 1 p.

Pachystethus oblivia, a pine leaf miner, is found on rare occasions attacking white pine in New York, and perhaps more frequently in Minnesota. Hard pines are the normal host. The insect feeds on needles just above the fascicle, and nearly cuts them off. The needles then turn brown and drop in July.

Hosley, N. W. 1928. **A preliminary study of borer damage in stacked white pine lumber.** Jour. Forestry 26: 888-891.

The pine sawyer *(Monochamus scutellatus* Say.) can cause serious damage to round-edge plank if uncontrolled. Lumber sawed between September 1 and March 1 in central Massachusetts was not infested with the borer. If sawing must be done during the danger period, damage may be avoided by sawing square-edge plank, by kiln-drying the lumber, or by making up the lumber into the finished product as soon as frass begins to appear.

Kamp, H. J. 1953. **Der Halsgrubenbock, ein gefährlicher Holzschädling.** Holz-Zentbl. 79 (152): 1626.

Describes the attack of *Criocephalus rusticus* on white pine in Germany. One tree (d.b.h. 40 centimeters) was infested from ground level to a height of 50 centimeters; another, 60 years old, showed infestation from ground level to 2 meters, the tunnels penetrating to a depth of 15 centimeters and reaching into the heartwood.

Kojima, Toshibumi. 1931. **Further investigation on the immature stage of some Japanese cerambycid-beetles with notes on their habits.** Imp. Univ. Tokyo Col. Agr. Jour. 11 (3): 263-308, illus.

Includes a description and account of habits of *Megopis tesserula,* for which white pine is listed as one of the hosts.

Lentz, G. H. 1929. **Further light on "tree seed farms".** Jour. Forestry 27: 424-425.

In at least 5 of 7 years a small beetle, *Conophthorus coniperda,* destroyed practically all of the 1-year-old cones in a virgin white pine stand at Warrensburg, N. Y., preventing the maturing of any useful quantity of seed.

MacAloney, H. J., and N. W. Hosley. 1934. **Experiments in simplified control of mound-building ants in forest.** Jour. Forestry 32: 1003-1006.

Carbon disulfide or ethylene dichloride, if properly used, will control the mound-building ant, *Formica exsectoides* Forel. One to two pounds of these chemicals are necessary for each mound. Treatment should be made in late fall or early spring when all ants are in the mound.

McGuffin, W. C. 1943. **New descriptions of larvae of forest insects. VII. *Pero, Nepytia, Caripeta* (*Lepidoptera, Geometridae*).** Canad. Ent. 75: 186-190.

Two of the three species described, *Pero morrisonarius* and *Neyptia canosaria,* have white pine as one of their less important hosts.

Minott, C. W., and I. T. Guild. 1925. **Some results of the defoliation of trees.** Jour. Econ. Ent. 18: 345-348, illus.

Growth and survival in relation to defoliation of oaks and white pine by gypsy moth was observed during a 10-year period. On the average, white pine was defoliated 10% annually with little loss of growth; but when a pine is completely defoliated, it nearly always dies.

Mitchell, H. L. 1939. **Preliminary notes on a method for the prevention and control of white grub infestations in nursery soils.** Black Rock Forest Papers 1 (14). 2 pp.

A series of tests showed that a solution of 0.8% acetic acid, applied at the rate of 0.75 quart per square foot of seed bed, is effective in controlling white grub infestation both before sowing and during the growing season. This treatment does not harm after-ripened white pine seed or seedlings. In addition, such treatments will control damping-off.

Monro, H. A. U. 1935. **Observations on the habits of an introduced pine sawfly *Diprion simile* Htg.** Canad. Ent. 67: 137-140.

White pine is the preferred host of *Diprion simile,* but this sawfly also attacks red, jack, and Scotch pines. In the severe winter of 1933-34, mortality was complete in cocoons more than 3 feet from the ground, and was least in those on the ground.

Parr, Thaddeus. 1943. **Voltage gradients in trees as an indicator of susceptibility to insect attack.** Jour. Forestry 41: 417-421.

Field and laboratory tests of voltage gradients were made on white and red pines, red spruce, pitch pine and beech. Healthy trees and those damaged by insect attack, partial uprooting, suppression, or other causes were studied. In healthy trees the gradient reached highest positive value in early spring, dropped fairly regularly to zero in August and dropped to negative values after that. Size, age, and species differences in healthy trees were slight, but trees of subnormal vigor showed divergence of voltage gradients in phase and degree.

Peirson, H. B. 1921. **The life history and control of the Pales weevil (*Hylobius pales*).** Harvard Forest Bul. 3, 33 pp.

Describes the life history, food habits and damage done to white pine seedlings by this insect. Chief attack is on seedlings 2 to 3 years old; 1-year seedlings are not damaged; and those 4 years or more are less seriously damaged. Pales weevil breeds in stumps, slash, logs, or lumber. Control is by prompt removal of logs and burning slash over stumps; advises to delay planting at least two growing seasons after cutting.

Peirson, H. B. 1922. **Mound-building ants in forest plantations.** Jour. Forestry 20: 325-335.

The death of trees and other vegetation surrounding these mounds is caused by the ants in their efforts to provide full sunlight on the nests. The pines are killed by injection of formic acid; other species are killed by this and other means. Control may be obtained by fumigating the nest with carbon bisulfide.

Perry, George S. 1930. **Tree damage by the red spider.** Jour. Forestry 28: 864-867.

Red spiders (*Tetranychus telarius* and other species) have often caused serious damage in Pennsylvania forest nurseries. One case of damage with 8% mortality is reported on a 14-year-old white pine stand with trees 10 to 20 feet high. Hot dry weather favors increase of the spiders; shade and irrigation help control them, and any contact insecticide is effective.

Plumb, G. H. 1950. **The adult feeding habit of some conifer-infesting weevils.** Canad. Ent. 82: 53-57.

Magdalis austera and *M. hispoides* were found feeding on the needles of white pine. The adult beetle emerges just as the young needles are breaking out of the sheath and drills through the scales into the succulent young needles, leaving a series of punctures. The part of the needle turns yellow and bends down at the point of injury. Later it falls off, so that the needles appear to have been fed on by lepidopterous or sawfly larva.

Schaffner, J. F., Jr. 1943. **Sawflies injurious to conifers in the Northeastern States.** Jour. Forestry 41: 580-588.

During the past decade, 14 species of sawflies have been abundant, at least locally, for one or more years. White pine is a preferred food species for three of these: *Acantholyda erythrocephala, Diprion simile* (introduced pine sawfly), and *Neodiprion pinetum* (white pine sawfly). A key to identification and a brief summary of the life history and general habits of the more important species are given. Control can best be maintained by silvicultural practices leading to fully stocked mixed hardwood-softwood stands.

Schimitschek, E. 1941. **Die Massenvermehrung des Kiefernspanners, *Bupalus piniarius* L., und seine Bekämpfung im Jahre 1940 in der Westslowakei.** Centbl. f. das Gesam. Forstw. 67: 25-46, 53-59.

An outbreak of *Bupalus piniarius* occurred in 1937 to 1940 in west Slovakia in pure even-aged stands of white pine, overstocked and unthinned. The attack was aggravated by an outbreak of the pine sawfly, *Diprion pini,* and many trees were killed. More than five healthy *Bupalus* pupae per square yard marked the danger limit and stands with double that figure were dusted by airplanes with two proprietary insecticides. Parasitism is also discussed.

Underwood, G. R. 1953. **Biennial cycle of injury by pine leaf chermes.** Canada Dept. Agr. Div. Forest Biol. Bimo. Prog. Rpt. 9 (3): 1.

Studies of *Pineus pinifoliae* in New Brunswick since 1946 reveal a biennial cycle of abundance and injury to white pine related to the pest's complex 2-year life cycle. A winged form (gallicola) goes from red spruce to white pine one year, and another winged form (sexupara) returns to the spruce the next. There are intermediate wingless forms.

Underwood, G. R. 1954. **Damage to white pine (*Pinus strobus*) by pine leaf chermes (*Pineus pinifoliae*).** Canada Dept. Agr. Div. Forest Biol. Bimo. Prog. Rpt. 10 (3): 1.

Measurement of increment cores from 186 white pines known to have been attacked since 1947 showed an average reduction in ring width of about 60% from 1943 to 1952. The pattern follows the biennial cycle of abundance of the insect, the decrease being limited to rings formed in the years after heavy attack.

United States Bureau of Entomology. 1927. **The relation of insects to slash disposal.** U.S. Dept. Agr. Circ. 411, 12 pp.

Slash attracts insects to cutover areas and serves as breeding material. The value of slash disposal in insect control is considered in each of the economically important forest-type insect complexes. Slash burning in white pine by the usual methods is held to have little value.

West, A. S. 1952. **Notes on Leconte's sawfly.** Canad. Ent. 84 (2): 59-61.

Notes on a heavy infestation of *Neodiprion lecontei* on white and red pine in Ontario. In 1946 both species were attacked; in some cases white pine was heavily infested, while neighboring red pine was free or nearly so ,indicating selective oviposition. In 1947-48 the infestation was extremely light and was limited to white pine.

STRUCTURE AND PROPERTIES

Aleksandrov, V. G., and K. Iu. Abesadze. 1927. **[Developmental sequence of bordered pits in pine tracheids.]** Russ. Bot. Obshch. Zhur. 12 (½): 183-196, illus.

Reports studies on wood structure of white pine and other pine species. (In Russian.)

Alvarez-Novoa, Jose C., Holger Erdtman, and Gosta Lindstadt. 1950. **Constituents of pine heartwood. XVIII. A note on cryptostrobin, an isomer of strobopinin from the heartwood of *Pinus strobus* L.** Acta Chem. Scand. 4. 390-391.

The process by which the new compound was isolated is described briefly, together with some of its properties. The compound may exist in the heartwood of white pine, but this is not certain.

Anderson, Ernest, Joseph Kesselman, and Emil C. Bennett. 1941. **Polyuronide hemi-celluloses isolated from the sapwood and compression wood of white pine, *Pinus strobus* L.** Jour. Biol. Chem. 140: 563-568.

These hemi-celluloses are common in hardwoods. White pine compression wood yielded larger amounts of them than normal sapwood. They were a complex mixture — apparently of two types. No definite conclusions could be reached about the size and structure of the molecules in the cell wall. A pectic material, probably a pectinic acid, was also isolated. It was apparently the same as that obtained from hardwoods.

Baker, Gregory. 1954. **The durability of Maine woods for fence posts—progress report.** Maine Univ. Forestry Dept. Tech. Note 33, 2 pp.

Data on white pine indicate a higher degree of durability than might be expected. The stock was cut from slim suppressed trees. In the outer 1-inch of radius the ring count ranged from 30 to over 40 rings per inch and the sapwood averaged less than ½ inch in thickness. After 8 years of service, only 20% of the white pine posts (4 to 4.5 inches in diameter at the ground) had failed.

Betts, H. S. 1929. **The strength of North American woods.** U.S. Dept. Agr. Misc. Pub. 46, 17 pp.

Actual and comparative values of wood properties for eastern white pine (from Shawano County, Wis.) and 128 other native American woods. Includes weight per cubic foot in green, air-dry, and kiln-dry condition, specific gravity when oven-dry, volume, radial and tangential shrinkage from green to oven-dry condition, bending strength, strength in compression parallel and perpendicular to the grain, stiffness, hardness, shock-resisting ability, and shearing strength parallel to the grain.

Brown, H. P. 1928. **Atlas of the commercial woods of the United States.** N.Y. State Col. Forestry Bul. 18, 6 pp., illus.

To assist all users of wood in species identification, photographs of the transverse sections of 57 tree species are shown at a magnification of 15 diameters. Plant No. 1 is *Pinus strobus.*

Brown, H. P., and A. J. Panshin. 1940. **Northern white pine, eastern white pine, white pine. *Pinus strobus* L.** *In* Commercial Timbers of the U.S.: 371-373. New York.

A brief description of general characteristics and properties, minute anatomy, and uses of white pine wood.

Brown, H. P., and A. J. Panshin. 1940. **The wood anatomy of northern white pine.** *In* Commercial Timbers of the U.S.: 94-109. New York.

Describes the anatomy as seen in the radial, tangential, and cross sections of white pine. Volumetric data for white pine wood and a detailed description of the longitudinal tracheid.

Burns, George P. 1920. **Eccentric growth and the formation of redwood in the main stem of conifers.** Vt. Agr. Expt. Sta. Bul. 219, 16 pp.

In white pine, redwood (compression wood) and eccentric growth usually occur together but not necessarily. Compression does not act as a stimulus causing the cambium to divide more rapidly and produce redwood. Pressure may be a factor in the differentiation of the annual ring into spring- and summer-wood, even in white pine and spruce where normally such differentiation is not especially marked. Production of redwood seemed in these experiments to be a morphogenic response to gravitation stimulus.

Carderera, E. 1950. **Estudio del *Pinus strobus* L. para su aprovechamiento celulosico.** Inst. Forest. de Invest. y. Exper. Bol. 23 (60): 19. Madrid.

Results of chemical and histological investigations are presented, including data on wood density, moisture content, and cellulose content, all of which indicate a good pulping species. Whie pine has already been planted in the coastal forests of northern and northwestern Spain. Wider use of it is recommended.

Carpenter, Charles H. 1931. **An atlas of paper-making fibres.** N.Y. State Col. Forestry Tech. Pub. 35, 7 pp., illus.

Photomicrographs of the fibres, including the tracheids, of eastern white pine.

Cockrell, Robert A. 1933. **A study of the screw holding properties of wood.** N.Y. State Col. Forestry Tech. Pub. 44, 28 pp., illus.

Ten species, including white pine, were studied to determine the effect of variable wood quality on the holding power of flat-headed, 1-inch No. 6, 8, and 10 screws. Maple ranked first in holding power; and white pine was next to last. This property is proportional to the first power of the specific gravity of the wood. Dry wood was 50% stronger than green in screw-holding strength. Data are given by species, showing force in pounds for side, end, and shear pulling of screw positions in wood.

Condon, E. U. 1945. **The self-ignition temperature of partially charred wood.** U.S. Bur. Standards, 6 pp., illus.
Results with grooved, partially charred white pine blocks and other materials were compared with results of previous tests on uncharred materials. The self-ignition temperature of white pine was 217° C. if partially charred, and 264° C. if uncharred. Test procedures are described.

Coppick, S., and E. C. Jahn. 1943. **Nitrated wood: fractionation and molecular magnitudes.** Indus. Engin. Chem. 35: 890-894.
A laboratory study of wood fractions found in nitrated wood of eastern spruce and white pine and of various pulp products of these species. A combination of solution and precipitation methods in water, acetone, alcohol and other organic solvents showed that crude nitrated wood of 5% lignin content had viscosities and average equivalent molecular weights comparable to those of nitrated bleached cotton linters. However, the material of large molecular size in wood can be broken down further by bleaching, or extraction by hot water and hot alcohol. This indicates easily severed linkages between cellulose and lignin, carbohydrates, and possibly glucosides and hemicelluloses.

Findlay, W. P. K. 1942. **Resistance to decay of *Pinus strobus*.** Emp. Forestry Jour. 21: 134.
Results from standard laboratory tests indicated that there is little difference in the resistance to decay of the timber of white pine and *P. silvestris;* it is concluded that timber of white pine should be classified as moderately resistant to fungal decay.

Forsaith, C. C. 1926. **Eastern white pine.** *In* The Technology of New York State Timbers. N.Y. State Col. Forestry Tech. Note 18, 285-287.
A brief description of white pine wood anatomy.

Fowler, W. F., and W. M. Harlow. 1940. **Infra-red photo-micrography reveals plant cell wall structure.** Paper Indus. 21: 1159-1160, illus.
In infrared microphotographs of the sapwood of white pine, stained with neocyanine, it was possible to distinguish clearly the primary cell walls and the true intercellular substances as separate components of the compound middle lamella.

Garratt, George A. 1931. **The mechanical properties of wood.** 276 pp., illus. New York.
Tabulates for white pine and about 50 other commercial species the tensile and compressive strength perpendicular to the grain, compressive strength parallel to the grain, shearing strength parallel to the grain, results of static and impact bending, hardness, and cleavage strength tests. Gives specific gravity, weight per cubic foot, percentage of shrinkage on drying. Working stresses are tabulated for joists, planks, beams, stringers, and columns under various use conditions. All measurements were made on unseasoned wood.

George, Harry O. 1933. **The effect of low temperature on the strength of wood.** N.Y. State Col. Forestry Tech. Pub. 43, 18 pp.
In tests with the wood of white pine, black ash, and sugar maple it was concluded that wood is stronger in a frozen state than at ordinary temperatures. Influence of cold on strength of wood is largely a matter of change of state of the moisture contained in the cell walls. Strength increase due to freezing is greater above than below the fiber saturation point. Ice damage to standing timber may be attributed entirely to excessive load and wind effects since the influence of cold is to lessen the danger of breakage.

Greguss, P., and I. Varga. 1950. **Xylotomischer Bestimmungsschlüssel der Pinus-Arten.** Univ. Szeged. Bot. Inst. 162 pp.
The transverse, tangential, and radial sections of the xylem of 68 pine species are briefly described. On the basis of ray tracheid wall and pit characteristics, the species are divided into nine groups typified by: *Pinus cembra, P. strobus, P. aristata, P. massoniana, P. radiata, P. pinea, P. sylvestris, P. banksiana,* and *P. ponderosa.* Both Cembra and Strobus have smooth-walled ray tracheids with one and sometimes two or three circular to rectangular pits in the radial walls. The tangential walls are usually pitted. In Cembra the pits occur one over the other, but in Strobus they occur side by side.

Hausbrandt, L. 1953. **(Comparative investigation on the anatomical structure of the wood of the native and some foreign pines grown in Poland.)** Rocz. Dendrol. Polsk. Tow. Bot. 9: 1-64.
The nine species of pine investigated include white pine, which is characterized by: (1) smooth-walled ray tracheids which are few in number, (2) one or two semi-bordered pits in the common radial wall of ray parenchyma and longitudinal tracheids.

Lewis, Frederic T. 1935. **The shape of the tracheids in the pine.** Amer. Jour. Bot. 22: 741-762, illus.
Reconstruction from serial transverse sections of the wood and cambium of white pine show that the constituent cells have an average of 18 to 22 contacts with neighboring cells, and present a geometrical form deducible from the effects of tension in their walls. Their basic shape is that of a 14-hedral fiber, oriented with *edges* above and below (prosenchyma, as contrasted with parenchyma, which has *facets* above and below). By an outward buckling of the shafts of the fibers, or an inward growth of the extremeties, the 14-hedral fibers cross one another at their tips, becoming 18-hedral or 22-hedral, according to degree of curvature.

Markwardt, L. J. 1930. **Comparative strength properties of woods grown in the United States.** U.S. Dept. Agr. Tech. Bul. 158, 38 pp.
Supplements Newlin and Wilson (1917) by tabulating comparative values or indexes for mechanical properties of the important commercial woods, including white pine. Working stresses are also tabulated.

Markwardt, L. J. 1941. **Aircraft woods: their properties, selection, and characteristics.** Forest Prod. Lab. Mimeo. R1079, 51 pp., illus.
Strength values of various woods for aircraft design for a 15% moisture condition and a 3-second duration of stress are given, and various factors affecting these values are discussed. The toughness-test method of selecting wood is discussed and a table of acceptance values for several species is included. White pine is among the species that may be considered with red, sitka, and white spruce for use in highly stressed parts such as wing beams.

Matzke, Edwin B., and Robert L. Hulbary. 1942. **An analysis of the wood of the three commercial species of white pine.** Torrey Bot. Club Bul. 69: 573-582, illus.
The pits of the ray parenchyma cells in contact with the tracheids are described in detail. Figures show that they are large and oblong in *Pinus strobus,* somewhat smaller and lemon-shaped in *P. lambertiana,* and intermediate in *P. monticola.* In ray parenchyma pit characters, *P. monticola* is a little closer to *P. lambertiana* than to *P. strobus.* In other features, both gross and microscopic, *P. monticola* is intermediate between the other two.

Myer, J. Edson. 1930. **The structure and strength of four North American woods as influenced by range, habitat and position in the tree.** N.Y. State Col. Forestry Tech. Pub. 31, 39 pp.

The texture and strength properties of wood samples of white pine, hemlock, sugar maple, and white oak did not differ by geographic range; but position of sample within the tree affected these properties. In white pine, texture was not coarse at the 16-foot point and became finer toward the stump and top. Specific gravity of pine decreased rapidly from stump to 16-foot level. Strength of pine woods under compression was not greatly affected by position in the tree.

Newlin, J. A., and R. C. Wilson. 1917. **Mechanical properties of woods grown in the United States.** U.S. Dept. Agr. Bul. 556, 47 pp., illus.

The mechanical properties of the wood of some 50 commercial species, including white pine grown in Wisconsin, are reported. Small clear pieces from 16 white pines were used in the tests on air-dry wood and pieces from five trees were used for the green condition tests.

Olson, A. R., N. V. Peletika, and H. W. Hicock. 1947. **Strength properties of plantation-grown coniferous woods.** Conn. Agr. Expt. Sta. Bul. 511, 27 pp.

Tests show that in most cases plantation-grown wood is slightly weaker than forest-grown wood. If young plantation wood is to be used where strength is a factor, it may be necessary to specify larger dimensions (computations shown). The relative weakness results from a lower specific gravity caused by rapid diameter growth. As plantations grow older, the strength of the wood will improve.

Pillow, M. Y. 1953. **How growth of white pine affects its properties for matches.** U.S. Forest Prod. Lab. Rpt. D1950, 4 pp., illus.

Matchsticks consisting only of spring-wood have very little strength; hence fast grown lumber with three to five rings per inch should not be used for matches. The ideal match block should have uniform growth of 10 to 15 rings per inch. Some types of compression wood, with larger angles of fibre strands, also should be avoided because of brittleness.

Risi, J., and M. Brule. 1946. **Utilization of conifer branches.** Perfumery and Essential Oil Rec. 37 (3): 78-79. (Abs. from Amer. Perfumer and Essential Oil Rev.)

A table is included showing the physiochemical properties of the needle oils of *Thuja occidentalis, Pinus strobus, Abies balsamea, Picea mariana,* and *Tsuga canadensis.*

Rol, R. 1932. **Note sur un essai de classification du genre Pinus d'apres des caracteres tires de l'anatomie du bois.** Rapp. 65eme Congr. Soc. Savantes 1932: 333-341, illus.

Studies of pine-wood anatomy provide a species and section classification based on medullary-ray characters and pits in summer-wood tracheids. White pine and species in the section Strobus have few smooth-walled ray tracheids, thin-walled ray parenchyma, single (rarely as many as two or three) large subrectangular pits in the cross-field with the longitudinal tracheids and numerous pits in longitudinal tracheids in the summer-wood.

Schall, W. M. 1943. **An investigation of the presence of siliceous rods in the secondary wall of woody tissue.** Madroño 7: 8-14.

From studies with white pine and a variety of other species it is concluded that silica, in the form of continuous siliceous skeletons, is not present in the secondary wall of woody tissue, and that the silica content of such tissue is such a small percentage of the total weight of the wood that it could not have an effect greater than that of other minerals on the differential swelling or shrinking of wood.

Steiner, A. J. 1944. **Fire-hazard classification of building materials.** Underwriters' Lab. Res. Bul. 32, 34 pp.

Results of limited and preliminary fire-hazard classification tests are given for untreated and surface-coated white pine and other materials. Classification factors were established for maximum flame spread, fuel contributed, and smoke density. The results are compared on a numerical basis with the performance of untreated red-oak lumber classified as 100 and asbestos-cement board as 0.

United States Forest Products Laboratory. 1952. **Shrinking and swelling of wood in use.** U.S. Forest Prod. Lab. Rpt. R736, 10 pp.

A general account of dimensional variation in wood and some of the effects of shrinking and swelling. Shrinkage values of some 40 softwoods (including white pine) and 90 hardwoods are given. How to minimize dimensional variation during and after manufacture is discussed, and recommended moisture contents for various wood items at the time of installation in different climatic areas are tabulated.

United States Forest Products Laboratory. 1952. **The white pine group.** Forest Prod. Lab. Tech. Note 215, 3 pp.

A brief description of the wood properties of the three principal white pines.

Venet, J. 1951. **Etude de la resistance mechanique des bois de bois de mine.** Ecole Nat. des Eaux et Forets Ann. 12: 323-408, illus.

White pine is one of many species tested extensively for suitability as mine timber. The effect of origin, season of cutting, storage period, defects, percent sapwood, width of annual ring, and other structural characteristics on static bending strength and compressive strength parallel to the grain are given in tables and charts. Notes were made of deformations within the elastic limit and of those affecting fibers after rupture.

Wershing, Henry F., and I. W. Bailey. 1942. **Seedlings as experimental material in the study of "redwood" in conifers.** Jour. Forestry 40: 411-414.

Young seedlings of white pine form redwood during their first season of growth and are favorable material for the study of redwood under controlled conditions. The application of indole-acetic acid to the hypocotyledonary stem of such seedlings produces directly or indirectly (1) enlargement of cortical cells, (2) accelerated cambial activity, and (3) a much modified type of tissue differentiation in the xylem. The xylem formed by the stimulated cambium is commonly of the redwood type.

Anonymous. 1954. **White pine production and export.** Timber Canada 14 (5): 22-23.

In 1909 the annual production of white and red pine in Canada was 1.3 billion board feet. By 1932 production had dropped to a low of 180 million board feet. Since then the production of white pine alone has increased irregularly to 392 million board feet in 1949 and more rapidly to 449 million in 1951. Ontario has always produced the bulk of Canadian white pine. About one-third of the total production is exported to the United States. The United Kingdom annually takes about 25 million board feet, mostly pattern stock; and the Caribbean area is the other major export market.

Cronk, C. P. 1936. **Forest industries of New Hampshire and their trend of development.** 237 pp. N.H. Forest and Recreation Comn.

A survey of forest industries, showing the changes since 1912. A detailed list of all wood-using plants is included. The number and variety of small firms that depend on white pine is shown. The difficulties arising from low-quality pine and poor manufacturing are also discussed.

Erickson, E. C. O. 1950. **New England eastern white pine as a house-framing material.** U.S. Forest Prod. Lab. Rpt. R1241, 4 pp., illus.

Second-growth white pine, when properly braced and nailed, makes wall panels that are comparable in stiffness and rigidity to the denser southern pines. Diagonal sheathing is most desirable but a system of let-in, continuous-piece, diagonal bracing in combination with horizontal sheathing is nearly as good. With 8-inch sheathing, three 8-penny nails should be used at each stud crossing.

Fernow, B. E. 1905. **The movement of wood prices and its influence on forest treatment.** Forestry Quart. 3: 18-31.

A discussion of the progress of wood prices in world and local markets, with remarks on the behavior of eastern white pine prices.

Hill, Arthur. 1898. **The pine industry in Michigan.** Mich. Polit. Sci. Assoc. Pub. 3 (4): 110-120.

Of historical interest, this paper briefly reviews the course of the pine industry, the volumes cut and remaining, the increasing cost of the lumber, and the position of the industry. A plan is set forth for the State to take ownership and reforest pine stumplands.

Jahn, Edwin C., and C. V. Holmberg. 1939. **Relation of lignin content to the strength of paper and boards. I. Literature survey and progress report.** Paper Trade Jour. 109 (13): 30-35, illus.

Reviews literature on structure and chemical composition of the cell wall and their relation to pulping and paper-making quality. Gives a brief progress report on experiments to determine how method and degree of delignification affect the chemical composition of white pine pulp and the strength characteristics of sheets made from standard pulps.

Jensen, Victor S., C. E. Behre, and A. O. Benson. 1940. **Cost of producing white pine lumber in New England.** U.S. Dept. Agr. Cir. 557, 40 pp., illus.

Production cost per thousand board feet declines rapidly with increase of tree size, levelling off at 20 inches in diameter. Partial cutting does not increase operating costs in accessible stands. Value of graded lumber from pruned logs is 50% greater than from unpruned logs. Square-edged lumber reduces mill scale about 21%, but increases sale value about 28%. Graded-lumber values exceed mill-run prices.

Kingsbury, R. M., F. A. Simmonds, and E. S. Lewis. 1949. **Bleaching groundwood pulps with hypochlorites.** Pulp and Paper Mag. Canada 50 (5): 98-102.

Calcium hypochlorite is a satisfactory bleaching agent for groundwood pulp of various hardwoods but not for that of white pine.

Kitazawa, George. 1946. **A study of adhesion in the glue lines of twenty-two woods of the United States.** N.Y. State Col. Forestry Tech. Pub. 66, 55 pp.

Resorcinol-formaldehyde glue lines with eastern white pine rated fair in comparison with other species. Ureaformaldehyde glue lines rated poor with eastern white pine. An analysis is made of the shear strength of the woods at failure and of the types of failure.

Ladell, J. H. 1953. **High-temperature kiln-drying of Canadian woods: report of exploratory investigations—softwoods.** Forest Products Lab. Canada 0-170. 11 pp., illus.

Seasoning tests at temperatures over 212° F. were made on boards of white pine and four other species. Drying was 3 to 6 times faster than by conventional methods. Seasoning defects were negligible, apart from case-hardening, which was uniformly severe; but conditioning treatment after the cooling period gave fairly satisfactory results. Moisture-content variation was outside acceptable limits. In bending-strength tests, white pine showed a 5% reduction in strength.

Larson, Agnes M. 1949. **History of the white pine industry in Minnesota.** 432 pp., illus. St. Paul, Minn.

The growth and decline of the industry is considered in detail. The impact of the industry on social and economic developments in northern Minnesota is well illustrated, and it is shown that these influences extended throughout the Middle West. The numerous sources of material are indicated in footnotes.

Levy, John, and Edwin C. Jahn. 1939. **Effect of mechanical gelatinization on the solubility of wood in cuprammonium solution.** Paper Trade Jour. 109 (23): 45-49.

The solubility of white pine mechanical pulp in standard strength cuprammonium solution was increased by mechanical gelatinization, which increased the surface area of the wood; and by alkaline treatment, which softened and swelled the wood particles and removed slight amounts of lignin and hemicelluloses.

Marquis, Ralph W. (n.d.) **Lumber used in manufacture—1940.** Summary tables. U.S. Forest Serv., 48 pp.

Wood used in manufacture is summarized three ways: by products and kinds of wood, by States and kinds of wood, by products and States. Each summary shows the amount of lumber, veneer, logs and bolts, and total board feet of wood used. In the first two summaries, northern white pine (including red and jack pine) is shown separately. Selected statistics are compared with equivalent statistics for 1928 and 1933 taken from earlier reports.

Merrick, Gordon D. 1951. **Wood used in manufacture—1948.** U.S. Dept. Agr. Forest Resource Rpt. 2, 66 pp.

A report on the fourth of a series of similar surveys; others were made in 1928, 1933, and 1940. U. S. Wood consumption for fabricated products during 1948 is tabulated by product, state, and kind of wood. The total consumption of eastern white pine (including red and jack pine) was 678 million board feet. Tabulations show the amounts lumber, veneer, and bolts used, by products and by state.

National Lumber Manufacturers Association. 1935. **Lumber grade-use guide for softwood and hardwood lumber in building and general construction. Pamphlet X. Northern white pine, Norway pine, eastern spruce manufactured and graded under rules and supervision of Northern Pine Manufacturers Association.** Nat. Lumber Mfr. Assoc., 8 pp., Minneapolis.

The recommended grade of lumber for about 200 use-items in 14 separate groups is given with descriptions of the standard grades and tables of standard thickness and widths.

Northeastern Lumber Manufacturers Association. 1939. **Grade-marking of northeastern softwoods. Grade-use recommendations for northern white pine and eastern spruce.** Northeast. Lumber Mfr. Assoc., 8 pp., illus.

The regulations governing grade marking of northeastern softwoods, effective September 1, 1939, are set forth; and specific grades are recommended for many use-items arranged in 17 groups.

Northeastern Lumber Manufacturers Association. 1950. **Northeastern white pine: its grades and uses.** Northeast. Lumber Mfr. Assoc., 38 pp., illus.

A presentation of the uses of white pine and the volumes produced. Includes photographs and descriptions of typical boards in each grade of white pine lumber.

Raney, William F. 1935. **Pine lumbering in Wisconsin.** Wis. Hist. Mag. 19: 71-90, illus.

Exploitation of white pine in Wisconsin began along Lake Michigan and on the State's eastern rivers about 1835. Large-scale operations began on the Wisconsin, Black, Chippewa, and St. Croix Rivers about 1850. The development of the industry in each of these drainages is discussed. By 1875 white pine was practically exhausted and the mills shut down, moved farther west, or turned to hemlock and hardwoods.

Reynolds, R. V., and A. H. Pierson. 1937. **The aggregate cut of American lumber, 1801-1935.** Jour. Forestry 35: 1099-1101.

The total cut of lumber during this 135-year period is estimated as 2,200 billion board feet with a total value at cutting time of about 36.5 billion dollars. Of this total, about 459 billion board feet was eastern white pine, with some red and jack pine intermixed. Half of the white pine was cut in the Lake States.

Risi, J., and L. P. Amiot. 1948. **Etude de la penetration de solutions aqueuses d'uree-dimethyloluree dans les principaux bois Quebecois et de l'influence de ce traitment sur quelques-unes de leurs proprietes mecaniques.** Quebec Min. Terres et Foret Bul. 13, 38 pp.

Eight softwoods and 12 hardwoods from Quebec province were impregnated with urea and dimethylolurea and tested for penetration of the resin and for changes in some mechanical properties. A uniform penetration was practically impossible to achieve. Among the most easily impregnated species was white pine. Increased resistance to compression parallel to the grain was noted. All species showed a considerable increase in hardness. Resistance to shock was decreased in all cases.

Risi, J., and M. Brule. 1945. **Etude des huiles essentielles tirees des feuilles de quelque coniferes du Quebec.** Quebec Min. Terres et Forets Bul. 9, 52 pp.

A report of experiments in the distillation of essential oils from the needles of white pine and four other conifers native to Quebec. Details are given of the methods and equipment used. Recommendations are made covering commercial distillation. Maximum yields are obtained from January to April. Average yield from white pine is 0.6 to 1.0%. The quality of oil obtained in Quebec is as good as that obtained from the same species elsewhere.

Risi, J., M. Brule, and M. Picard. 1945. **Etude de quelques proprites des charbons de bois du Quebec se rapportant a leur utilisation comme carbinant dans les Gazogenes.** Quebec Min. Terres et Forets Bul. 6, 30 pp.

Eastern white pine was among 16 species studied. The charcoal from all coniferous species is much more friable than that from hardwoods and is therefore unsuitable for use as producer-gas fuel.

Rogers, J. S. 1949. **Tannin from northeastern barks.** Paper Trade Jour. 128 (16): 21-23.

The tannin content of the bark of nine Northeastern species was determined. That of white pine was less than 6% — not enough to justify commercial processing.

Salomon, M. 1953. **The accumulation of soil organic matter from wood chips.** Soil Sci. Soc. Amer. Proc. 17: 114-118.

Experiments on the addition of wood chips of white pine and black oak in combination with nitrate nitrogen to Merrimac sandy loam seem to show that the treatments have no practical effect on soil properties or plant growth. Analyses for organic content, available nitrogen, pH, and growth of beets and spinach in the soil are presented.

Schafer, E. R., and A. Hyttinen. 1949. **Groundwood pulping of five common northeastern farm woodland species.** U.S. Forest Prod. Lab. Rpt. R1743, 5 pp.

Groundwood pulps were made from white pine, yellow birch, red and white ash from a naturally occurring mixture of the hardwoods, and from a mixture of the pine and the hardwoods. White pine gave a pulp equal in strength and brightness to commercial groundwood pulps. The strength and brightness of the mixed pine and hardwood pulp showed that groundwood suitable for newsprint might be made by grinding mixtures containing up to 35% hardwoods by volume.

Schwartz, H., and C. Greaves. 1944. **Production of pine tar by the destructive distillation of Canadian softwoods.** Canada Forest Prod. Lab. 14 pp., illus.

Laboratory and commercial-scale tests revealed that pine tar of a quality suitable for use in the manufacture of tires from natural rubber could be obtained in commercial quantities from selected resinous Douglas-fir and white-pine waste wood. However, the supply of suitable white pine waste wood at eastern mills was not sufficient to justify commercial production.

Skoggard, C. O., and C. E. Libby. 1946. **Experimental sulphite pulping of eastern white pine (*Pinus strobus* L.).** Paper Trade Jour. 123 (4): 41-46.

Best results were obtained in a single-stage process using a sodium-base liquor. The pulp was characterized by high bursting strength, good folding endurance, low tearing resistance, and high ether solubility. Higher screened yields and slightly easier bleaching pulps were obtained than with the other liquors tested.

Steer, Henry B. 1948. **Lumber production in the United States 1799-1946.** U.S. Dept. Agr. Misc. Pub. 669, 233 pp., illus.

Tabulates, by years, the volume and value of lumber production of the states and regions. Tabulations by species also.

Treen, E. W. 1936. **The northeastern lumber industry.** Jour. Forestry 34: 755-758.

Discusses the steps being taken by the Northeastern Lumber Manufacturers' Association to improve and strengthen the markets for northeastern lumber. These steps include stabilization of grading rules for white pine and spruce, contact wih public purchasing agencies, adjustment of freight rates, promotion and publicity, national affiliation, and conservation.

United States Forest Products Laboratory. 1938. **Pertinent facts on salvage of New England timber.** U.S. Forest Prod. Lab. R1183, 28 pp.

A preliminary guide for handling salvaged material. It covers log storage, lumber conversion and seasoning, log grades, scales, cutting specifications, marketing, preservative treatments, and other subjects. Special attention is given to white pine.

Wangaard, Frederick F. 1935. **The strength and behavior of mortise and tenon joints at different moisture contents.** N.Y. State Col. Forestry Tech. Pub. 47, 30 pp.

White pine, black cherry, and sugar maple were used in the tests. Mortise and tenon joints should be assembled at the average moisture content the joint will experience in use — 9% in New York State.

Wentling, J. P. 1907. **Woods used for packing boxes in New England.** U.S. Forest Serv. Cir. 78, 4 pp.

Nearly 82% of the lumber used in New England's 344 box factories in 1905 was white pine. The total consumption for this use was more than 600 million board feet. Other statistics for the box industry are also given. Although a severe shortage of second-growth white pine was not imminent in 1905, it was urged that plantations be established on waste land to be available when present supplies are exhausted.

White Pine Bureau. 1917. **Classified recommended uses for white pine in house construction and white pine standard grading rules of the Northern Pine Manufacturers Association, Western Pine Manufacturers' Association, and the White Pine Association of the Tonawandas.** 197 pp. The White Pine Bureau, St. Paul.

Compiled for architects' use in specifying white pine lumber, the book contains recommendations for grade of lumber in each of the classified uses and for three classes of cost within each use. The standard grades are described and illustrated, distinguishing features are set forth, recommended uses listed.

White Pine Bureau. 1917-20. **The white pine series of architectural monographs.** Vols. 3-6, The White Pine Bureau, St. Paul.

Devoted to early American houses and other building constructed of white pine, this series is primarily photographic, with short texts and sometimes specifications for the buildings. The series aims to promote the use of white pine in housing.

Williams, Charles T. 1906. **Cursory review of lumber conditions as they have affected the box manufacturing business in the past ten years.** South. Lumberman 51 (603): 54.

From 1896 to 1906 the supply of white pine timber in the Lake States shrank from plentiful to near the point of exhaustion. In 10 years the price of No. 4 box lumber increased from $6 to $18 and the quality has become much poorer. In the same period the price of boxes rose only 65%. White pine is still the mainstay of the box industry and the supply is still good in New England, but the use of wood from the South, Pacific Coast, and Canada is increasing.

SEASONING : PRESERVATION QUALITY AND GRADES OF PRODUCTS

Baker, Gregory. 1951. **The effect of log storage time on development of brown stain in northern white pine (during kiln seasoning).** Maine Univ. Forestry Dept. Tech. Note 8, 1 p.

No stain developed in wood sawed and seasoned within 24 hours of felling. Logs piled on skids in the woods for 42 days or more developed a considerable amount of brown stain. Depth of penetration increased with increased storage time.

Baldwin, H. I. 1953. **Control of borers in green logs.** N.H. Forestry and Recreation Comn. Fox Forest Notes 52, 2 pp.

Benzene hexachloride at the rate of 1¾ pounds of the pure gamma isomer in 50 gallons of No. 2 fuel oil will protect logs and bolts 3 to 4 months. Addition of 2% pentachlorophenol will give better control of sap stain. About 12 gallons of solution are required per thousand board feet of logs.

Berry, A. G. V., and J. C. Cater. 1945. **Interim report on trials of copper naphthenates and mercuric naphthenates as wood preservatives.** Empire Forestry Jour. 24: 233-235.

Reports the 6-year results (1939-45) of tests of these metallo-organic salts that were dissolved in gas-oil, a petroleum distillate, and applied by the open-tank method. White pine was effectively protected against termites and fungi by these chemicals and partly protected by gas-oil alone.

Bess, Henry A. 1944. **Insect attack and damage to white-pine timber after the 1938 hurricane in New England.** Jour. Forestry 42: 14-16.

Discusses the abundance of and damage done by bark beetles, borers, bark weevils, and ambrosia beetles to white pine logs and trees. Standing timber and trees uprooted but with many roots intact suffered little or no damage by 1940. Water storage and piling logs on dry sites at some distance from wind-felled trees gave good protection. Chemical sprays and covering decked logs with straw and boughs gave some protection, but costs were greater than benefits.

Brophy, M. J. 1941. **Prevention of checks in air-seasoning thick white pine.** Canada Forest Prod. Lab., 4 pp. Ottawa.

In addition to the established practices in air-seasoning, the author believes these points should help to prevent checks: (1) box-pile lumber of uneven lengths to prevent an overhang at the rear of the pile; (2) pile a variety of widths close together (but not touching) at the sides of the pile, leaving a single center flue 8 to 12 inches wide; (3) use relatively thin cross pieces; and (4) take special precautions with lumber that is cut in the autumn, when it is more susceptible to checking than in the summer.

Brown, Frederick L. 1953. **Mercury-tolerant penicillia causing discoloration in northern white pine lumber.** Forest Prod. Res. Soc. Jour. 3: 67-69.

Two fungi isolated from timber treated with mercury compounds were shown to be the cause of a deeply penetrating blue discoloration of white pine sapwood. These fungi, *Penicillium cyclopium* and *P. crustosum,* were found to be several times more tolerant of mercury than *Ophiostoma coeruleum.* The fungi caused no significant decrease in toughness of discolored specimens and seemed to destroy only epithelial tissue.

Davis, E. M. 1940. **Lumber from old-growth vs. lumber from second-growth in *Pinus strobus*.** Jour. Forestry 38: 877-880.

Second growth from New England produced about one-fourth as much select lumber and one-half as much high-common lumber as did the old-growth from Minnesota. The medium-common yield was about the same for both but the second growth produced more than twice as much of the marginal low-common. Shake and decay were common defects in old growth but almost negligible in second growth. Knots were sounder and larger in second growth, these being the determining defects in most of the second growth.

Desjardins, A. 1945. **Des sechoirs et due sechage artificiel des bois de construction.** Quebec Min. Terres et Forets. 23 pp.

A general account of the design and operation of kilns and the process of seasoning. Schedules are given for kiln-drying white pine and other native softwoods and hardwoods of various dimensions.

Fritz, C. W. 1929. **Stain and decay in lumber-seasoning yards, with special reference to methods of prevention.** Canada Dept. Int. Forest Serv. Cir. 27, 15 pp., illus.

Discusses the requirements of good seasoning-yard practices and points out conditions that are conducive to decay and stain. Although applicable to any species, this circular was written particularly for the white pine industry of eastern Canada where losses due to blue stain alone run up to $1 million a year (1928).

Harkom, J. F. 1942. **Creosote treatment of white pine piles.** Amer. Wood Preserv. Assoc. Proc. 28: 149-150.

Tests indicate that it should be possible to treat white pine piles with 12 pounds of creosote per cubic foot of wood after 4 to 8 weeks of air-seasoning. There was no checking in the heartwood as is usually the case with red pine treated in this way.

Henderson, H. L. 1932. **Dry kiln practice.** N.Y. State Col. Forestry Tech. Pub. 38, 196 pp.

A manual on the operation of kilns, including kiln schedules for eastern white pine and many other species.

Hodson, E. R. 1906. **Rules and specifications for the grading of lumber adopted by the various lumber manufacturing associations of the United States.** U.S. Forest Serv. Bul. 71, 127 pp.

Presents, among other rules and specifications, the 6th edition (1906) grades and rules for grading pine lumber. These were developed by the Northern Pine Manufacturers' Association. Although these standard grades were used chiefly for white pine; they were also used for red pine and hemlock produced in the upper Mississippi Valley and Wisconsin regions by members of this association.

Long, George S. 1925. **An old report on the grading of white pine lumber.** Amer. Lumberman 2619: 46.

A lumber inspection report made in the Lake States in 1880 is presented and discussed. This report, which showed up the wide discrepancy in lumber grading at various mills, led ultimately to the setting up of standard northern white pine grades.

Lorenz, Ralph W. 1946. **A convenient method for cold-soaking fence posts in a pentachlorphenol solution.** Jour. Forestry 44: 520-522, illus.

Specifications and costs for the construction of a plant to treat fence posts by the cold-soaking method are presented with brief comment on the effectiveness of pentachlorphenol solutions in preventing decay of white pine posts. The posts in service remained sound for at least 3 years, while untreated posts were no longer serviceable after 2 years.

MacAloney, H. J. 1935. **Prevention of damage to round-edged white pine lumber by wood-boring insects.** U.S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 21, 2 pp.

Three species of borers are involved: the sawyer beetles *Monochamus scutellatus* Say and *M. notatus* Drury and the black-horned pine borer *Callidium antennadum* Newm. The first two attack green logs and lumber; the other attacks seasoned or partially seasoned material. Lumber sawed in fall and winter should be used the next spring and early summer; lumber sawed in spring should be used before September. No sawing should be done in June, July, or August unless there is immediate use for the material.

Mississippi Valley Lumberman's Association. 1904. **Rules for the grading of pine and hemlock lumber . . . adopted by the Mississippi Valley Lumberman's Association and the Wisconsin Valley Lumberman's Association, and Western Pine Shippers' Association.** Ed. 5, 72 pp. Minneapolis.

Gives early lumber-grading rules for pine and hemlock; describes standard grades, giving examples. The association was organized in 1891 and published the first edition of rules in February 1895. After the 6th edition in April 1906 the Mississippi Valley and Wisconsin Valley Lumbermen's Associations were merged to form the Northern Pine Manufacturers' Association. These rules were used as models for standardizing lumber grading throughout the country.

Nash, Robley W. 1954. **Protection of logs and round-edge planking from wood borers by benzene hexachloride sprays.** Maine Forest Serv. Forest Insect Note 1, 4 pp.

Large-scale applications of benzene hexachloride as emulsions, solutions, and suspensions were made in 1953 on white pine logs and round-edge planking to prevent damage by wood borers. Applications of 1 pound of gamma isomer of benzene hexachloride in 50 gallons of mixture were made by high-pressure hydraulic sprayers. A complete analysis of the results was not made, but careful observations showed that very good control was obtained.

Northeastern Lumber Manufacturers Association. 1937. **Standard grading rules for northern white pine (*Pinus strobus*—northeastern type) and Norway pine (*Pinus resinosa*—northeastern type).** Revised 1948. Northeast. Lumber Mfrs. Assoc., Inc., 39 pp., illus. New York.

Gives lumber specifications for three select grades, five common grades, knotty pine, No. 1 cuts, log-run square-edge, log-run round-edge, and round-edge box sides. Supplementary instructions and definitions are included and standard lumber sizes and milling patterns are described.

Northern Hemlock and Hardwood Manufacturers Association. 1947. **Official grading rules for northern hardwood and softwood logs, tie cuts, box bolts, shingle bolts, chemical logs, bolts, and cordwood.** North. Hemlock and Hardwood Mfrs. Assoc., 12 pp. Oshkosh, Wis.

Describes method of grading and rules for four grades of white pine logs, giving dimensions and defects allowable. Grading rules for other products are given.

Northern Pine Manufacturers' Association. 1948. **Standard grading rules for northern white pine, Norway pine, jack pine, eastern spruce, western white spruce, balsam, tamarack, aspen lumber.** (Reissued 1951.) North. Pine Mfrs. Assoc., 36 pp.

The grades include five select grades, six common grades, three special lumber grades, five dimension and timber grades, as well as two shop, two door, and two lath grades.

O'Neil, William J. 1953. **Hurricane break in New England conifers.** Jour. Forestry 51: 290.

"Hurricane break," a lateral fracture of wood fibers, caused degrade of white pine lumber produced by the New England Timber Salvage Administration following the 1938 hurricane. Overall, the degrade amounted to only 1%, but it varied from place to place and was as much as 10% in some yards. Careful inspection of logs and rough boards did not reveal the damage, but it was evident in planed boards.

Simpson, L. J. 1949. **Borer injury in burned timber.** Canada Dept. Agr. Forest Insect Invest. Bimo. Prog. Rpt. 5 (3): 1.

Spring fires result in the greatest amount of borer damage (from *Monochamus scutellatus*) in fire-killed spruce, balsam fir, and white pine in New Brunswick. Trees burned in late summer or autumn are generally too dry for borers to attack them next spring; but trees killed in the spring, if left standing, are subject to further severe boring early in the following season. Damage is more severe in white pine than in spruce or balsam, and after ground fires than after crown fires. Timber burned before August should be salvaged immediately and white pine should have the highest priority.

Spurr, Stephen H., and Roger B. Friend. 1941. **Compression wood in weevilled northern white pine.** Jour. Forestry 39: 1005-1006, illus.

Development of compression wood was studied in 19 weevilled sections of white pine. The pith offset was always greater than the external offset because of eccentric growth. Compression wood was formed just below the weevilled node under the new leader. It was a serious defect in the lumber sawed from the center of the sections. There was a well correlated direct relation between the offset of the pith and the horizontal extent of the compression wood. It is emphasized that the more rapidly the bole straightens after weevilling, the less the defect.

Walters, Charles S. 1943. **Treating fence posts with pentachlorphenol-fuel oil solutions.** Jour. Forestry 41: 265-268.

White pine and a number of other softwood and hardwood species have been successfully cold-soaked in equipment usually available to a farmer at reasonable cost. A post about 5 inches in top diameter and with a volume of 1 cubic foot will absorb ½ gallon of the 5% solution. Care should be taken to protect hands and arms from the solution.

Walters, C. S. 1948. **Preservative treatment of white pine fence posts at low temperatures.** Jour. Forestry 46: 180-183.

Fifty round white pine posts were peeled, dried, and cold-soaked 144 hours in a 5% solution of pentachlorophenol in light fuel oil. Air temperature ranged from —18 to 22° F. and that of the solution from 14 to 26° F., but there was little evidence of sludging or precipitation in the solution. Absorption was 2.90 pounds per cubic foot after 48 hours and 3.70 pounds after 144 hours. Deep penetration of the sapwood was essentially complete after 48 hours.

Walters, C. S., and H. W. Fox. 1952. **Hand-peeling fence posts compared to mechanical peeling.** Ill. Univ. Agr. Expt. Sta. Forestry Note 31, 2 pp., illus.

A total of 530 white pine poles were barked, 271 by hand and the rest on the Illini post peeler, a revolving-head abrasion barker. The machine was twice as fast as hand-peeling, but neither method was practical on frozen wood.

Walters, C. S., and W. L. Meek. 1951. **Report on project 301-A. Preservative treatment of fence posts by cold soaking in pentachlorphenol-fuel oil solutions.** Ill. Univ. Agr. Expt. Sta. Forestry Note 28, 4 pp.

Two lots of treated white pine posts were still free of decay after more than 8 years' service. The greatest percentage of decayed posts (44%) was in a lot cold-soaked only 6 hours.

Zabel, Robert A. 1953. **Lumber stains and their control in northern white pine.** Jour. Forest Prod. Res. Soc. 3 (3): 36-38.

Staining is generally common in logs and lumber between May 15 and September 30. Logs should be pond-stored or treated with chemical preventative within 24 hours of cutting. Lumber should be treated with preventatives within 24 hours after sawing and should be stacked quickly for rapid drying, with protection from rain. Solid piling is permissible for several weeks if chemical concentrations are doubled.

Zabel, Robert A., and Clifford H. Foster. 1949. **Effectiveness of stain control compounds on white pine seasoned in New York.** N.Y. State Col. Forestry Tech. Pub. 71, 17 pp.

A comparison was made of the relative effectiveness of 13 common sap-stain preventatives, using 1,000 test sticks (1 x 1 x 12 inches) and 20,000 board feet of lumber, all freshly sawed. The most effective chemicals or chemical mixtures were ethyl mercury phosphate with sodium pentachlorophenate, and sodium pentachlorophenate with borax. Poor piling and wane on boards will result in stain regardless of treatment.

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ECONOMIC GUIDES for blister-rust control in the East

by Robert Marty

U. S. FOREST SERVICE RESEARCH PAPER NE-45
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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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ECONOMIC GUIDES for blister-rust control in the East

A Need for Guides

WHITE PINE blister rust *(Cronartium ribicola,* Fischer) is a virulent and potentially serious disease of eastern white pine *(Pinus strobus,* L.) Control of this introduced rust has been carried on since about 1910 in the eastern United States. Today, after more than 50 years of control effort, the occurrence of blister rust in this region is gratifyingly infrequent. Because of effective and continuing control programs, blister rust has been brought under control, and is not now a serious threat to pine management in most areas of the East. Yet, control must continue if blister rust is to remain under control in the future.

Several efforts have been made in years past to provide control personnel with guides and standards for determining the conditions under which control is a worthwhile undertaking. Better guides can enhance the economic effectiveness of control programs by aiding control personnel in recognizing good control opportunities, and in avoiding poor ones. These guides aid program administrators as well, because they are a necessary adjunct to determining the amount of control justified for a district, state, or region.

Evaluating Control Opportunities

The essential decision facing a blister-rust-control worker, as he examines a control area, is whether to undertake a control treatment now or to delay treatment at least until the next examination, say 10 years hence. He must decide whether the additional value saved by immediate treatment is great enough to warrant the cost of the treatment. If it is, then immediate treatment is indicated: if it is not, then postponement is the better course.

First-Order Conditions

There is no economic return to rust control unless: the protected pine will be harvested; the protected pine is more than 20 years from harvest; and ribes are present and there are signs of current pine infection.

These are three first-order conditions that must be met by all pine stands scheduled for treatment. Some pine stands will not be harvested when they mature because of inaccessibility or because they are on lands where harvest is prohibited. Protection in such cases must be justified on other grounds than those considered here. Pine stands within 20 years of harvest will not lose any appreciable amount of stocking from further rust infection because it takes nearly that long for rust to kill heavy poles and small sawtimber. And of course there is no point in considering immediate treatment where no ribes population occurs in or near the stand, or where there is no sign of current infection.

Required Information

If the three first-order conditions are met, control will result in some benefit. The next phase in evaluation is to determine whether this benefit is great enough to justify the cost of control. Eleven items of information about the control area are needed to use the evaluation procedure presented here:

1. *Observed infection rate.* The percentage of pine first infected with blister rust 6 to 10 years before examination.
2. *Climatic hazard.* Within the high climatic hazard zone, or the

low hazard zone (fig. 2).

3. *Pine density.* The average number of uninfected free-to-grow pines to be found on occupied plots 1/200 of an acre in size.
4. *Stand type.* Planted or natural.
5. *Ownership class.* Public or private.
6. *Site index.* Less than 60 feet in 50 years, between 60 and 80 feet, or more than 80 feet.
7. *Stand-age class.* The average age of the pines being protected, by 20-year classes 1-20 years, 21-40 years, 41-60 years, and so on.
8. *Years to harvest.* Assumed rotation age (table 1) less the midpoint of stand-age class.
9. *Weevil-control class.* Control has been or is being practiced, or not.
10. *Stocked pine area.* That part of the total pine area made up of occupied plots as defined in 3 above, in acres.
11. *Control cost.* The number of man-days of labor and supervision required to destroy ribes within the control area, multiplied by 26 dollars and divided by the stocked pine acreage.

Some of these items of information are readily available from maps and records, or are immediately evident from examination. Other items, particularly infection rates and pine density, are best established by measuring sample strips or plots distributed over the pine area.

Figure 1 summarizes the relationships that determine the value saved by immediate control. With the information specified above, this figure can be used to estimate the present worth of value saved per stocked acre. Value saved is compared with the control cost per stocked acre (item 11) to determine whether or not immediate control is justified. Figure 1 also gives three intermediate estimates that may be of interest: the rate of infection to be anticipated during the next decade, the proportion of stocked area that will be denuded during the next decade, and the loss in harvest volume this will entail.

An Example

The following section discusses these evaluation procedures and relationships in detail. But a brief example may be helpful at this point in providing an overall understanding of the mechanics of the evaluation process.

Consider a 560-acre control area on private land in northern New York, containing a 210-acre natural pine stand mostly in the

1-20 year age class. A survey of the area shows that about 3 percent of the pines were fatally infected with blister rust during the 5-year period beginning 10 years before examination. Since this control area is in the high hazard climatic zone, the upper right-hand graph in figure 1 indicates that there is likely to be about a 15-percent infection rate during the next decade.

The stocking in this pine stand is irregular, with some 20 percent of the pine area in openings of 1/200 acre or more, or stocked with species other than pine. On the average, there are two uninfected free-to-grow pines per 1/200 acre over the remaining 80 percent of the pine area actually occupied by pine. The upper left-hand graph in figure 1 indicates that, with an expected infection rate of 15 percent, and a present density of two pines per 1/200 acre in the occupied pine area, this natural stand is likely to lose about 7 percent of its stocked area during the next decade if control is postponed.

Measurements on a few older pines scattered over the pine area indicate that the 50-year site index for white pine is somewhere between 60 and 80 feet. The lower left-hand graph in figure 1 shows that a 7-percent loss in stocked area, on a private ownership of medium site quality, means that a little over 3,000 board feet of harvest volume will be lost per stocked acre if control is delayed.

Seventy years is the rotation age assumed in this analysis for

Table 1. — *Average net sawtimber yield at harvest for fully stocked stands of eastern white pine, by site index and ownership class*

50-year site–index class (*feet*)	Ownership	Rotation age assumed	Average net yield per acre of sawtimber for fully stocked stands, International ¼" rule
		Years	*M board feet*
Less than 60	Private	80	25
	Public	100	35
60-80	Private	70	45
	Public	90	65
More than 80	Private	60	60
	Public	80	85

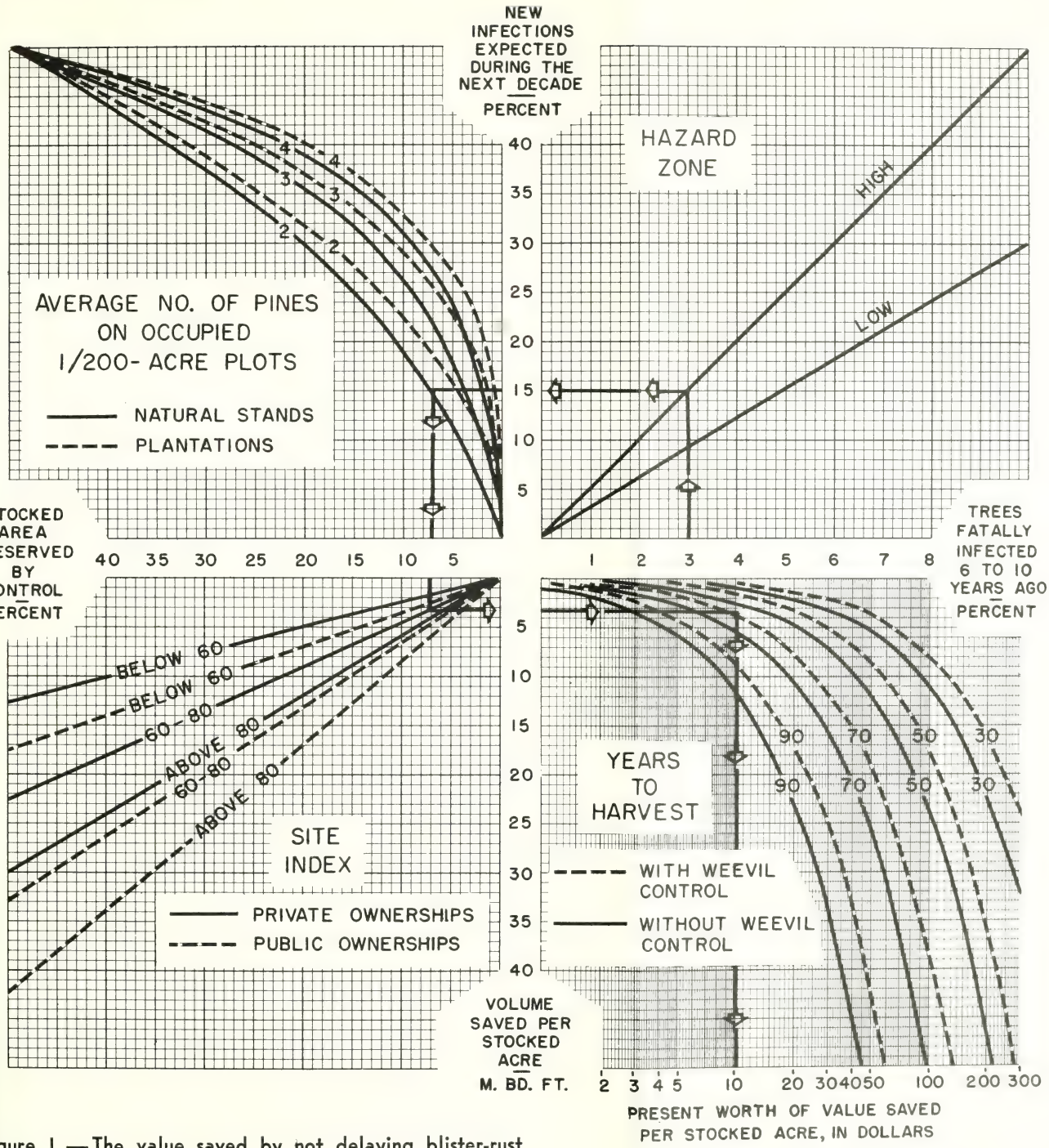
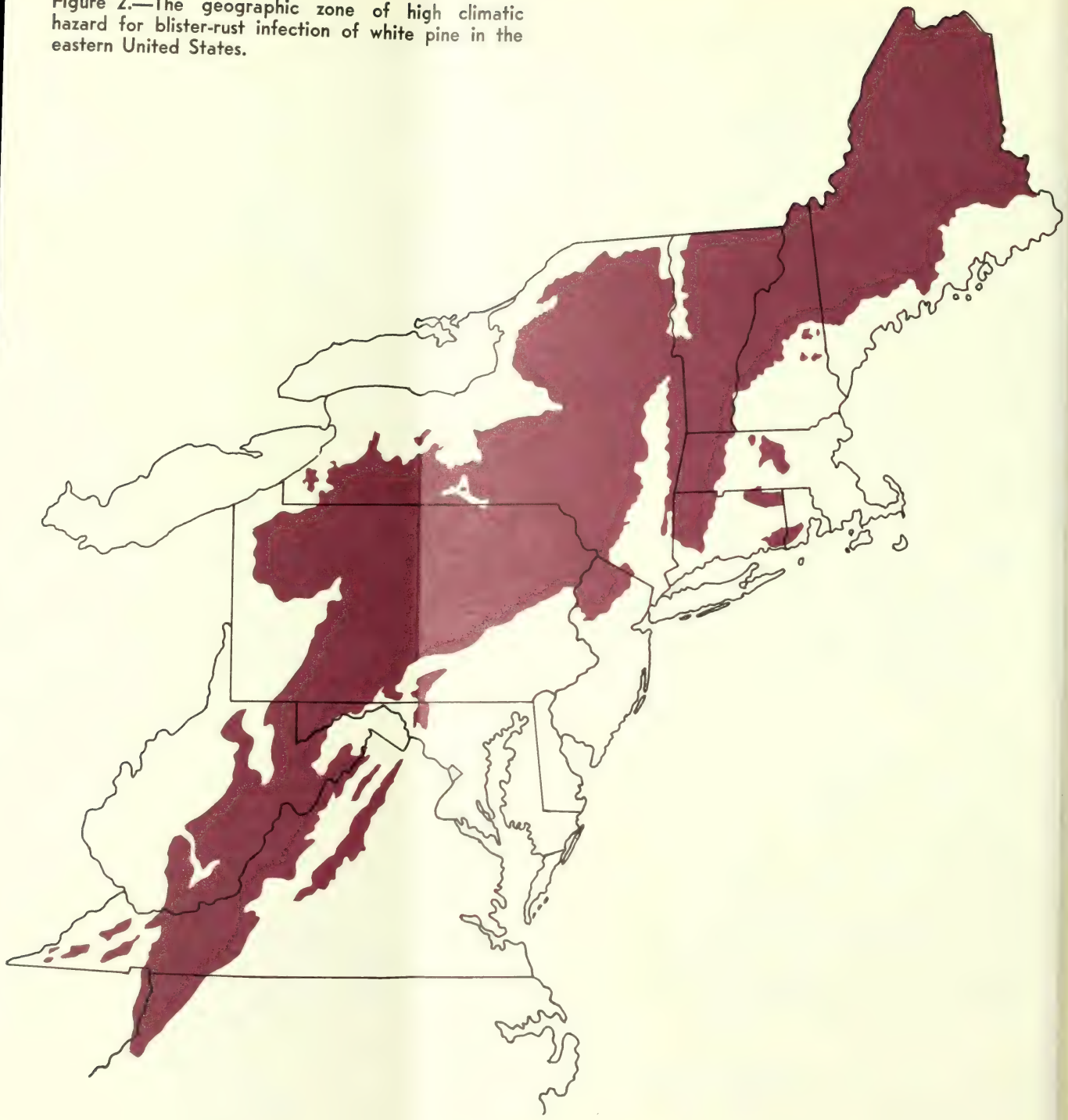


Figure 1.—The value saved by not delaying blister-rust control.

Figure 2.—The geographic zone of high climatic hazard for blister-rust infection of white pine in the eastern United States.



pine on private ownerships of medium site quality (table 1). Since the stand is now about 10 years old, about 60 years remain until harvest. Weevil control has not been undertaken in this pine area. The lower right-hand graph in figure 1 shows that under these circumstances the present worth of the harvest value that can be saved by control is about $10 per stocked acre. This value results from multiplying the volume saved by a unit value of $30 per thousand board feet, and discounting this harvest value for 60 years at 4 percent.

The final task is to compare this value saved with expected control cost. It will take a 3-man crew about 5 days to treat this control area thoroughly. This means about 15 man-days, at a unit cost of $26 on the basis of recent experience, or a total cost of $390 for the control area. Since there are 168 acres (0.8x210) actually stocked by pines in the pine area, this works out to a treatment cost of only a little over $2 per stocked acre. So in this example, immediate control would save much more than it would cost and is amply justified on economic grounds.

Relationships and Procedures

Infection Buildup

The first task in estimating value saved is to determine the rate of infection to anticipate during the coming decade. Where rust is present in pine stands, the average number of trees infected per year typically increases with time, if there is no control. In a recent survey of blister-rust incidence, sample plots with different treatment histories were compared to determine how much infection rates increased after treatment.[1] Survey results are only tentative on this point, but there was little question that infection rates did increase with time, and that this increase was more rapid in areas of high climatic hazard than elsewhere.

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[1] Marty, Robert. LOW AVERAGE BLISTER RUST INFECTION RATES MAY MEAN HIGH CONTROL COSTS. U. S. Forest Serv. Res. Note NE–28, 7 pp. Northeast. Forest Expt. Sta., Upper Darby, Pa., 1965.

The survey data indicated that the infection rate for the decade after examination will probably average about five times the rate observed for the 5-year period beginning 10 years before examination, in areas of high climatic hazard, and will typically average about three times greater for stands in low hazard areas.

These estimates of infection buildup are rather gross averages, and in the same general area there is considerable variation among stands having similar observed rates of infection. These differences in infection buildup are caused by differences in microclimate, in the species and distribution of ribes, in the size and distribution of pines, in the presence or absence of soil disturbance during the intervening period, and in other factors that cannot be taken into account at present. Figure 2 shows the location of the zones of high and low climatic hazard in the East. This figure was adapted from Charlton[2] and several unpublished sources.

The infection buildup relationship is shown in the upper right-hand graph in figure 1. A 5-year sample period beginning 10 years before examination is used to establish recent infection history because infections beginning during this period are more easily discernible than new infection at the time of examination. The sample-period infection rate must be established by actually checking a sample of trees from the pine area and noting how many were first infected during this period. Since infection rates are usually below 5 percent, a large number of trees must be examined to establish the infection rate accurately, and sample trees must be well distributed over the pine area.

Stocking Losses

Blister rust kills individual pines and groups of pines, thus reducing the proportion of the area actually stocked with pines. However, there is probably no significant reduction in yield until rust has created in the pine stand openings of at least 1/200 acre.

To see the effect of infection on stocking and yield, picture a pine stand subdivided into square plots 1/200 acre in size (fig. 3).

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[2] Charlton, John W. RELATING CLIMATE TO EASTERN WHITE PINE BLISTER RUST INFECTION HAZARD. U. S. Forest Serv. Eastern Region, 38 pp., illus. Upper Darby, Pa., 1963.

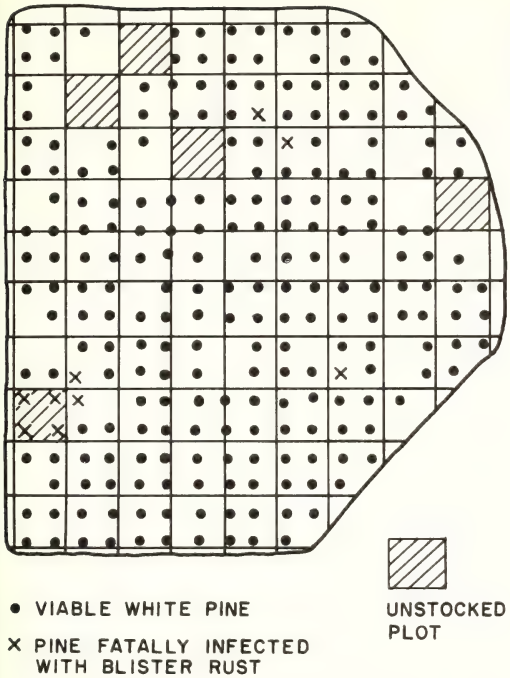

Figure 3. — Hypothetical distribution of pine stocking and rust infection in a young plantation.

If this stand is a young, unthinned plantation, originally planted at an 8-foot spacing, most of the plots will contain three or four pines. There will, of course, be some plots with only one or two pines, and even some without any pine, due to planting failures and subsequent mortality, including that caused by blister-rust infection in past years.

What is important as far as yield loss is concerned is how many of the plots now occupied by pines will be denuded by blister rust during the coming decade. If blister rust kills some but not all of the pines in a plot, probably no significant yield loss will result, because there is still at least one crop tree to occupy the plot. But if rust kills all the pine on a plot, then the percentage of the stand area that will support pine at harvest has been reduced, and so yield will be reduced as well. If 10 of the 1/200-acre plots are denuded per acre during the next decade (fig. 3), this means about a 5-percent reduction in stand area occupied by pine and a similar loss in harvest yield.

The proportion of the pine area that will be denuded by blister rust in the decade after examination depends on the rate of infection during that period and the density and distribution of pine in the pine area. This relationship is shown in the upper left hand graph of figure 1. The graph shows that, as average density decreases, more area is denuded by a given amount of infection — on the average. Thus, lightly stocked stands are more seriously affected by rust because, in the extreme case where there are only 200 pines per acre, nearly every tree infected means a loss in harvest volume.

On the other hand, heavily stocked stands can lose many trees without reducing the number of uninfected pines to a critical level. This relationship implies that infection may often be more serious and damaging in older, lightly stocked poletimber stands than it is in young, densely stocked stands of reproduction.

There is a separate set of curves for plantations and natural stands in figure 1. The curves show that natural stands have more area denuded by a given level of infection than plantations with the same average density of pine stocking. This is because the distribution of pine stocking is usually more regular in plantations than in natural stands, and this means that natural stands will have larger areas of critically light stocking than do plantations of the same average density.

These curves, showing the relationship between infection rate and area denuded, are based on specific assumptions. The curves for plantations assume that the pine stocking is evenly distributed and that the infection is randomly distributed over one-half the pine area. The curves for natural stands assume that pine stocking follows the Poisson distribution and, again, that the infection is randomly distributed over one-half the pine area.

It is necessary to estimate the average density of pine during control-site evaluation. This is done by taking a sample of 1/200-acre plots, well distributed over the pine area, and observing the number of uninfected free-to-grow pine on each. This sample should be taken at the same time, and in conjunction with, the infection-rate sample. Count as viable stocking only those pines that have not yet contracted a fatal blister-rust infection and are

free of other fatal insect and disease conditions as well. Also exclude pines that are shaded by trees of the more tolerant species shown in the following listing, unless a pine release treatment is planned for the stand: hemlock, balsam fir, spruce, maple, beech, yellow birch, and — for areas with site indices of 60 or better for pine — the oaks and hickories.

The density survey will provide two needed statistics, the proportion of sample plots without any viable pine stocking, and the average number of uninfected, free-to-grow pines on the remaining occupied plots.

Yield Losses

How much harvest yield will be lost if 10 percent of the stand area now occupied by pine is denuded by blister rust during the next decade? It is assumed here that 10 percent of the harvest yield will be lost under these circumstances, but what this means in board feet depends on stand growth rates and on rotation age. Table 1 shows how average net yield varies with site index and rotation age. These yield estimates are based on normal yield-table data, but are adjusted for an average level of volume loss due to weather and pest losses other than blister rust. Yields can be conditioned further by various silvicultural treatments, but these are ignored here. The yield estimates essentially apply to unmanaged stands.

Since the control worker cannot know what rotation age will actually be chosen at the time he examines the stand, rotation age is assumed here to be a function of both ownership and site index. Stands on poor sites are assumed to be held to age 80 by the typical private owner, to 70 years on medium sites, and to 60 years for good sites. Rotation ages on public lands are assumed to be 20 years longer on all sites.

For a given percentage of stocked area preserved by control, harvest volume saved increases as site index increases and is greater for public ownerships where stands are assumed to be held to older ages (fig. 1, lower left). The volume saved by control, shown in this graph, is expressed as an average saving per stocked acre.

Value Saved

The value of the additional yield that can be saved by early control depends on the stumpage value at harvest, the number of years to harvest, and the discount rate. Stumpage value per thousand board feet determines the total value of yield saved at the time of harvest.

The appropriate unit stumpage value for public programs is the conversion surplus for the stumpage, since this includes the addition to income for both the stumpage producer and the processor, and approximates the total increase in income for the economy. This unit value is assumed to be $30 per thousand board feet. This is somewhat higher than current stumpage prices in most market areas, but not unduly high when it is remembered that this value is for stands maturing many years hence, and includes the processor's profit margin in addition to stumpage price.

A second price assumption of $40 per thousand board feet is also used in this study. This price level was introduced to apply to stands that are being protected from white-pine weevil injury as well as from blister rust. The additional $10 is meant to be a conservative estimate of the increase in unit value that weevil control brings. The increase in volume resulting from weevil control is ignored, although this can also be substantial. The effect of weevil control is to make blister-rust control more effective because rust control saves more volume and value in an unweeviled stand. The crop trees preserved from blister-rust infection are of better quality in stands protected from weevil injury, and their merchantable volumes may be larger as well. A similar increase in unit value could be claimed for pruned stands, but this is not taken into account in this study.

Value saved at harvest must be discounted to the present in order to compare it with the cost of control. A 4-percent discount rate is used here because it approximates the rate of interest currently paid on negotiable interest-bearing securities of the United States. Public investments should return at least this rate of interest. The number of years that value saved at harvest must be discounted is given by the assumed rotation age less present stand age.

These relationships are shown in the lower right hand graph of figure 1. The graph shows that for a given saving in harvest volume, stands closest to harvest have the largest present worth of value saved. Once again, the present worth of value saved is expressed on a per-stocked-acre basis.

Comparing Value Saved with Control Cost

The present worth of value saved, by not delaying rust control 10 years, is to be compared with the estimated cost of immediate treatment. If the present worth of value saved is greater than the expected cost of control, then immediate control will produce enough additional harvest value to return more than 4 percent on control costs, and the operation is economically justified. If control cost exceeds the present worth of value saved, control is best postponed — at least until the next examination.

Control personnel are experienced and adept at estimating the crew-time required to destroy the ribes in and around pine areas. Two simple steps are needed to convert this total control-time estimate to an equivalent control cost per stocked acre. First total man-days must be converted to a per-stocked-acre basis. For example, if it will take a 4-man crew 2 days (a total of 8 man-days) to strip a control area of ribes, and the operation will protect a 50-acre pine area, four-fifths of which supports pine stocking, then the crew-time per stocked acre works out to 0.2 man-days (8 man-days ÷ 40 stocked acres). The final step is to multiply the estimates of man-days per stocked acre by $26, giving $5.20 per stocked acre ($26 x 0.2 man-days) as the control cost in this case.

The $26 per man-day is the average cost per man-day of Ribes eradication work in the states making up Forest Service Region Seven for the years 1961-63. It was compiled by dividing total zone and district expenditures for all rust control activities by the number of man-days spent in actual eradication work. Thus it includes costs of supervision, equipment, and other overhead expenses at the district and zone levels, as well as direct labor and materials costs.

Summary

The information in this paper provides an objective and reasoned basis for evaluating opportunities for blister rust control in white pine stands of the eastern United States. The evaluation procedures lead to an estimate of the value saved by instituting an immediate control treatment rather than postponing treatment 10 years. This estimate of value saved is discounted and compared with expected control cost. Immediate control is economically justified when the present worth of value saved exceeds the cost of control.

In developing this procedure, I have attempted to strike a reasonable balance between a complete consideration of all relevant determinants and ease in field application. Some determinants that are relatively unimportant, or are difficult to measure or predict, are ignored or held constant in the analysis. Other important determinants are treated as variables, and their values must be determined individually at each application. This will not be difficult for most variables, but some type of sampling of pine for infection rate and density seems unavoidable. All in all, then, these procedures mean that somewhat more time and effort will be required for the periodic examination phase of the rust-control program. This, I hope, will be amply repaid by its allowing subsequent control efforts to be directed more nearly toward those control areas that will benefit most.

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Survival and early growth of planted forest trees on strip-mine spoils in the anthracite region

by Miroslaw M. Czapowskyj
and William E. McQuilkin

SOIL TECH. & MGT. BR.

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Survival and early growth of PLANTED forest trees on STRIP-MINE SPOILS in the anthracite region

Preface

THIS is the second of several reports dealing with mine-spoil revegetation research in the Anthracite Region of Pennsylvania. The first report, published in 1964, was "A guide for screen and cover planting of trees on anthracite mine-spoil areas" (U.S. Forest Service Research Paper NE-22). Other reports, describing results of studies still in progress, are scheduled for publication in the future.

The Pennsylvania Power and Light Company, whose interest led to initiation of this project on anthracite mine-spoil revegetation in 1961, financed most of the research reported in this and the preceding report, and is continuing its financial support of the studies now in progress.

The Pennsylvania Department of Forests and Waters and the Pennsylvania Department of Mines and Mineral Industries made their records available as an aid in locating plantations established under the State's strip-mine laws. Also, Joseph Paddock and Con Postupack, contract planters, made their records available and personally helped find and identify many of the plantations in the field. This cooperation and assistance, without which this study would have been severely handicapped, is gratefully acknowledged.

Figure 1.—Many communities in the Anthracite Region are surrounded by a panorama of unsightly coal-mine spoils. This is Girardville, in Schuylkill County.

Introduction

THE Anthracite Region of Pennsylvania once was blessed with a wealth of natural resources. Verdant mountain landscapes, interlaced with sparkling streams, spread as far as the eye could see. Magnificent forests clothed the land, and for a time supported a great lumber industry. Underlying the synclines in massive folds of the rock formations were the world's finest deposits of anthracite coal.

Beginning in the early 1800's, the mining of these coal deposits expanded to become the dominant industry of the Region, reaching its peak in the period 1910-30. Production slumped during the depression of the 1930's, rose again somewhat during World War II, and then slid into a decline that has continued to the present day.

Until rather recently, practically all anthracite was mined by sinking shafts deep into the earth, and the landscape was marred only by huge piles of waste near the mine entrances and the coal breakers. Then, in the 1930's, large-scale strip-mining ushered in a new era in the exploitation of the coal resource. To get at the coal seams, the overburden was stripped off with great earth-moving machines, and open-pit methods were used to dig out the coal.

Open-pit mining no doubt bolstered the economic health of the anthracite industry, but it has had detrimental side effects: it disturbs considerably more land than deep mining, and leaves much more barren residue. Particularly since World War II, stripping has become increasingly predominant in anthracite production, and consequently landscapes in the coal fields are almost universally scarred by stripping operations.

According to a recent survey conducted by the Northeastern Forest Experiment Station of the U.S. Forest Service in cooperation with the Pennsylvania Power and Light Company, the total area classified as disturbed by mining up to 1962 approximated 112,000 acres. Of this acreage, 76 percent was due to strip-mining (Frank, 1964). More than half of the stripped land is practically devoid of tree cover. In all, 19 percent of the total area in the coal fields has been physically disturbed. The scarring of the land-

scape, the contamination of streams and reservoirs by acids, soluble iron, and silt, and the discomforts of windblown dust around active strippings — all conspire to create depressing conditions for people living in these areas (fig. 1).

The seriousness of the situation has long been recognized by public agencies, civic and private organizations, certain coal companies, and many individuals. It has long been recognized, also, that one of the most effective ways to correct the situation is to establish vegetation wherever possible on the disturbed areas.

In 1938 Stanley Mesavage, then forester for the Susquehanna Collieries Company, put in some small-scale tree plantings[1] that are believed to be the first planting trials on anthracite spoils. In 1940, C. E. Ostrom of the Allegheny Forest Experiment Station (predecessor of the present Northeastern Station) made a preliminary survey of the planting problem on anthracite spoils.[1] And in 1943, W. E. McQuilkin of the Northeastern Station conducted some greenhouse studies of spoil acidity and fertility.[1]

Neither Ostrom nor McQuilkin did further work on the spoil problem at that time. However, Joseph Paddock, forester attached to the Wilkes-Barre Chamber of Commerce, continued Mesavage's trials by making additional small plantings in the early 1940's. The first experimental plantings of a formal nature were started in 1944 by the Pennsylvania Department of Forests and Waters (Mickalitis and Kutz, 1949).

In 1947, the Legislature of the Commonwealth of Pennsylvania enacted the first anthracite strip-mining law (Commonwealth of Pennsylvania, 1947). This required strip-mine operators to post bond for their stripping operations. Upon completion of an operation, the operator was required to plant trees, shrubs, or grasses on the spoil area, or, at his option, to forfeit $60 per acre of the bond in lieu of planting. The Department of Forests and Waters administered the tree-planting section of this law until 1953. Then the law was amended (Commonwealth of Pennsylvania, 1953) and administration of tree planting became a function of the Department of Mines and Mineral Industries. In 1963, the law was again amended (Commonwealth of Pennsylvania, 1963). This latest amendment set considerably higher specifications for grading and leveling than the previous laws, and the portion of the bond designated to cover the planting was increased to $100 per acre. As before, an operator can forfeit this portion of the bond and be released from all planting obligations.

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[1] Unpublished records and reports on file at the Kingston unit of the Northeastern Forest Experiment Station.

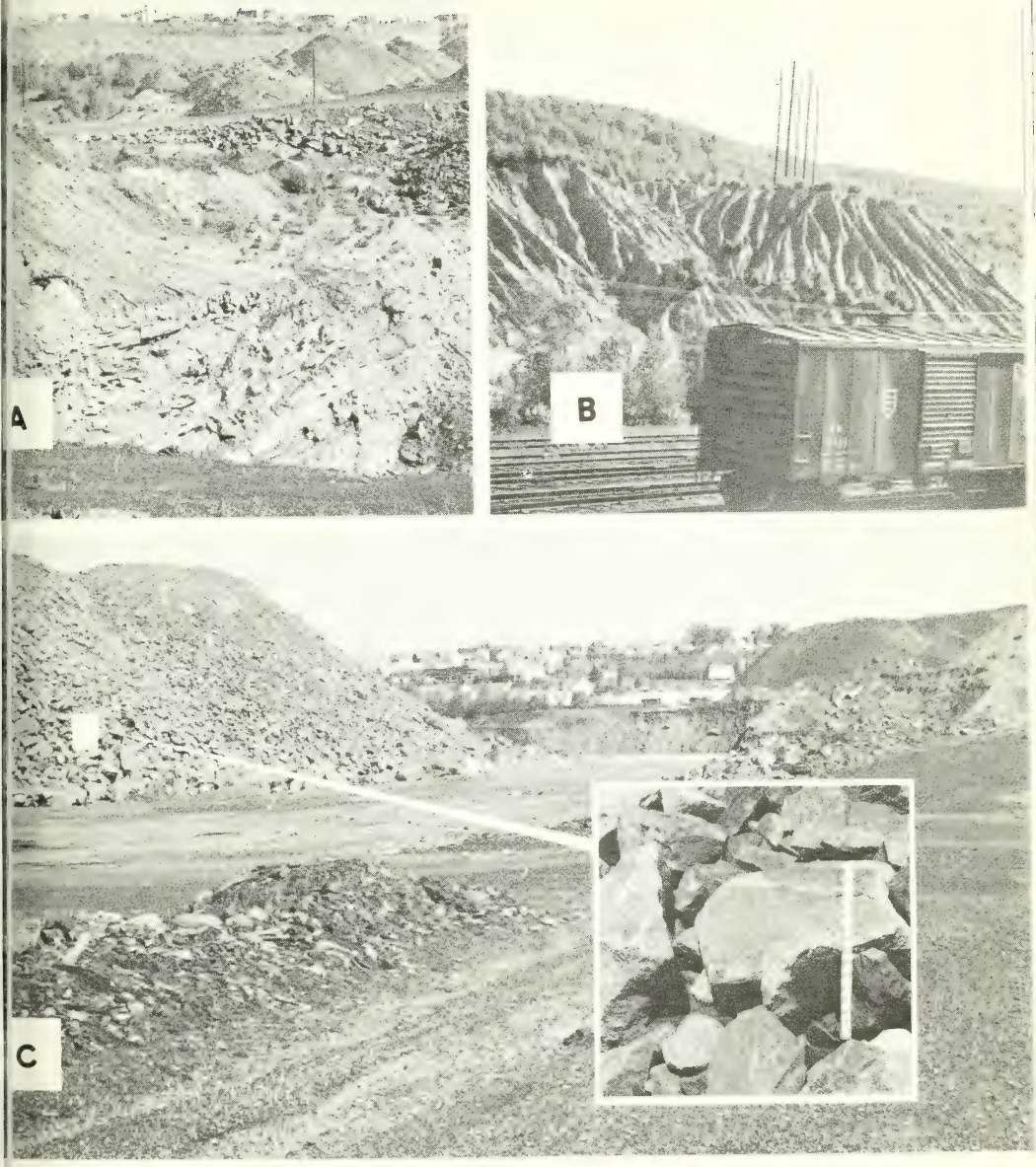

Figure 2.—Barren areas of strip-mine spoil. Although most spoils can be planted, portions of some old ungraded spoils are unplantable because of steepness of slopes as in A, right foreground; or erosion as in B; or excessive stoniness as in C, left background and inset. The grading provisions of the present strip-mine law do not permit such conditions to remain now when strippings are completed.

Although the experimental plantings by the Department of Forests and Waters during the period 1944-50 totaled some 200,000 trees, the results were not conclusive because of failures and losses to re-stripping. No other organized research had been done up to 1962. Hence both the planting under the strip-mining law and the occasional other private planting on spoil areas were based largely on experience on other types of sites.

Since the first small plantings in 1938, about 6 million trees were estimated to have been planted by 1962 in the four anthracite coal fields.[2] The results have been variable and erratic: some successes and partial successes, but also numerous failures (and losses to re-stripping). In 1962, when the present study was undertaken, the performance of these plantings was known only in a general way from informal observations. Survival and growth of the various species in relation to spoil types and other site conditions had never been drawn together in an organized study.

[2] Paddock, Joseph (Industrial Forester, Greater Wilkes-Barre Chamber of Commerce), personal communication, 1962.

The Study

In 1962 a survey-type study was conducted to evaluate the performance of forest tree species in established plantings on strip-mine spoils of the Anthracite Region of Pennsylvania. Plantations representing a wide range of site conditions in all four anthracite fields were examined.

The spoils were classified into four major types on the basis of parent material and acidity expressed as pH. Subdivisions within these types were recognized with respect to texture, aspect, slope position, and grading treatment. In each plantation that qualified for study, height measurements and survival counts were taken by species, and the spoil type and other site characteristics were recorded. Region-wide species performances were then correlated with spoil types and conditions.

The results of the study provide the basis for a preliminary guide for forest tree planting on the spoils. They also serve to identify the most crucial gaps in our knowledge and thus indicate where additional research effort should be directed.

Because anthracite and bituminous strip-mine spoils, although different in some respects, are basically similar, experience gained in a recent survey of established plantations on bituminous spoils (Davis and Melton, 1963; Hart and Byrnes, 1960) was utilized in planning the present study. Certain modifications were introduced to fit anthracite conditions.

LOCATING THE PLANTATIONS

The initial step in locating plantations was to check records on file with the Department of Forests and Waters and the Department of Mines and Mineral Industries. This was followed by an intensive search in the field with the assistance of contract planters and others having knowledge of past plantings. The number of suitable plantations was much fewer than originally anticipated. Furthermore, many of the plantations were so small, the spoil banks were so variable, and some species were so infrequently represented, that all hope of thoroughly sampling all the species across a balanced series of site variations had to be abandoned. Neverthe-

less the plantings did cover considerable variation in spoil material and other site factors, and much worthwhile information on the more commonly used species was obtained.

TREE AND PLANTATION DATA

For comparative data on height growth, measurements at a standard age were required. Moreover, both height and survival data are more meaningful if taken several years after trees are planted. In view of these considerations and the availability of plantings of different ages, 7 years was selected as the standard plantation age for most of our sampling. Six- and 8-year-old plantations also were sampled and lumped with the 7-year ones after converting the tree heights to a 7-year basis by adding or subtracting, respectively, the length of the last year's growth. All plantations in this 6- to 8-year age range that were suitable for our purposes were sampled.

A few older plantings, ranging from 10 to 18 years old, also were sampled. Most of these were in the northern field (Susquehanna–Lackawanna Valley area). The predominant species was black locust that had been planted in 1950. Older plantings of conifers were relatively scarce.

Sampling was done by plots of a single species. The usual plot in 7-year plantations comprised 25 original planting spots about equally divided between two or three adjacent rows. Where rows

Table 1.—*Species studied and number of plots taken, by species and age class*

Species		Plots in age classes (years)—		
Common name	Scientific name	7 (±1)	10-18	Total
Jack pine	*Pinus banksiana*	34	4	38
Red pine	*Pinus resinosa*	15	4	19
White pine	*Pinus strobus*	7	1	8
Virginia pine	*Pinus virginiana*	2	1	3
Pitch pine	*Pinus rigida*	2	2	4
Scotch pine	*Pinus sylvestris*	1	3	4
Norway spruce	*Picea abies*	43	—	43
White spruce	*Picea glauca*	27	—	27
Japanese larch	*Larix leptolepis*	21	3	24
European larch	*Larix decidua*	13	4	17
Black locust	*Robinia pseudoacacia*	—	11	11
All species		165	33	198

could not be identified, a plot of such dimensions that it could be assumed to have originally contained 25 trees at 6- x 6-foot spacing was roughly delimited. Where different species or different site conditions were represented in a plantation, two or more plots were taken in the same vicinity to sample the various situations.

A total of 198 usable plots were taken. Of these, 165 represented the 7-year age class, and 33 represented the 10- to 18-year class (table 1). Survival, vigor, and height were recorded for the trees on each 7-year plot as explained below:

Survival. — Starting at a randomly selected point, trees were tallied as living, dead, or missing in consecutive planting spots along the two or three selected rows until 25 spots had been checked. If rows could not be identified, the tally was based on an assumed distribution of planting spots. Trees that had recently been cut or destroyed but obviously had been living at that time were counted among the survivors.

Tree vigor. — Each tree included in the survival count was classified into one of five vigor classes: 1 — excellent; 2 — good; 3 — fair; 4 — poor; or 5 — very poor. Through use of the numerical ratings, average vigor for plots or other groups of trees could be calculated. The classes were based on color and density of foliage and on tree form, according to criteria defined in the earlier study in the bituminous region (Hart and Byrnes, 1960).

Height growth. — At each sampling point, 10 trees were measured for height to the nearest 0.1 foot. These 10 trees usually were selected among those in the survival count, and were distributed among the five vigor classes roughly in proportion to the distribution of all the survivors; that is, if one-third of the survivors fell in a given vigor class, three trees of this class were measured for height; if one-half the survivors fell in a given class, five of them were measured, and so on. Selections of trees within vigor classes were at random, except that overtopped trees or those with dead or broken terminals were not used. Some of the 25-spot plots checked for survival did not yield 10 trees suitable for height measurement; in these situations, enough other trees growing nearby under similar conditions were selected to provide a 10-tree sample. This was most often necessary for the plots with unidentifiable rows because high mortality often was responsible for the loss of row definition.

In the older plantings, the 11 plots of black locust were all 12 years old. Essentially the same data were taken here as in the 7-year plantings, except that survival was determined in 0.1-acre plots. The miscellaneous 10- to 18-year-old plantings of conifers

were so patchy and irregular that conventional plot methods of sampling were not suitable, and reliable estimates of survival could not be obtained. So we worked with whatever small groups of trees happened to be growing together under seemingly similar site conditions. Data taken for each such group included site characteristics, tree age, vigor, diameter of each tree at breast height to the nearest 0.1 inch, and height of at least six trees (if available) to the nearest foot.

DATA ON SPOIL AND SITE CHARACTERISTICS

Anthracite strip-mine spoils are composed of unstable debris of rock, coal, glacial till (mostly in the northern field) and surface soil. This material exhibits great diversity in physical and chemical characteristics; it varies widely not only from one spoil bank to another, but also on the same bank. Consequently, each bank is to some degree a unique problem. As tree-planting media these spoils have thus far received relatively little attention by soil scientists.

The initial step in collecting data on spoil characteristics was to devise a practical system of classification. The result was a rather simple classification in which four types of spoil were distinguished on the basis of the parent material. Our system was a modification of a classification developed by Bramble, Deitschman, and Keppler (1948) in their work on spoils in the Bituminous Region of Pennsylvania.

The four spoil types, number of plots in each, and a brief description are listed below:

Spoil type I — 51 plots: Coarse, black to dark gray, thin-bedded carbonaceous shales and slates, plus coal fragments. Gray to yellow thick-bedded slaty shales, sandstones, and conglomerate fragments are commonly associated.

Spoil type II — 73 plots: Pale gray to yellow, soft, thick-bedded shale and slate fragments, with black shales, and sandstones frequently intermixed.

Spoil type III — 39 plots: Gray to brown acid sandstone and conglomerate fragments. Slates and shales, together with glacial and stream deposits, often are associated. Extreme stoniness, with rocks 4 or more feet in diameter, is a common occurrence.

Spoil type IV — 35 plots: Basically glacial till and stream deposits, but sandstone, conglomerates, slates, and shale fragments may be associated. The coarse elements of the till and stream deposits vary from 2 millimeters to 2 inches in diameter. However, elements larger than 2 inches in diameter are occasionally present.

Each sampling point or plot was classified according to:

1. Spoil type: I, II, III, IV.
2. Grading treatment: graded or ungraded.
3. Degree of slope: steep—40-70 percent, medium—20-40 percent, or gentle—0-20 percent.
4. Aspect by cardinal compass points: north, south, east, or west.

In addition, a spoil sample of about 4 pounds was taken from each of three randomly selected spots in each plot. Sampling was restricted to bare surfaces.

In the laboratory, the following determinations were made:

1. *Acidity.* — determined on each sample with a Beckman Zeromatic pH meter. The pH tests were run on mixtures of the smaller rock fragments and finer material. Aqueous solutions 1:1 were used.
2. *Rock content.* — determined on composites of the three samples from each sampling point after the separate pH tests had been made. Rock content was the percentage of total air-dry weight that would not pass a 2-millimeter sieve.
3. *Texture of the soil fraction.* — also determined on the composite samples. The soil fraction was the material that passed a 2-millimeter sieve. Determinations were made by a modification of the Bouyoucos method (Bouyoucos, 1936).

Table 2 shows the distribution of the plots in each spoil type by textural classes of the soil fraction, and by four acidity classes. Note particularly in this table the tendencies toward finer or heavier textures, and toward lower acidity (higher pH), in type IV.

Table 2.—*Distribution of plots in each spoil type, by textural classes of the soil fraction and by four acidity classes*

oil pe	Textural classes					Acidity (pH)				Average acidity
	Sand and loamy sand	Sandy loam	Loam	Clay loam	Sandy clay loam	4.0 and lower	4.1 to 5.0	5.1 to 6.0	6.1 and higher	
	— Percent of plots —					*— Percent of plots —*				*pH*
	4	90	2	2	2	20	63	8	9	4.4
I	0	68	1	9	21	8	65	15	12	4.8
II	8	69	2	3	18	0	80	10	10	4.8
V	3	43	26	20	8	0	14	80	6	5.3

Results

Because it was impossible to find all species of the same age under all environmental conditions on all spoil types, only limited use could be made of statistical methods of data analysis. The conventional analysis of variance could not be used for comparing survival and growth among species or among different site categories. Therefore the study results are presented in a set of tables in which the data on survival and growth are summarized, by species, without statistical evaluations.

SURVIVAL AND GROWTH OF 7-YEAR-OLD PLANTINGS

Average survival and average tree height are shown by species for all 7-year sample plots in tables 3 and 4, respectively. Figure 3 depicts some of the same data graphically.

In table 3, the plots of each species are broken down into four survival classes: very good — 81-100 percent; good — 61-80 percent; adequate — 41-60 percent; and poor — 0-40 percent. Under each genus, the species are listed in descending order by number of plots studied.

Table 4 shows, besides average heights, the ranges in height, the growth in 1962, and average tree vigor according to the previously noted numerical scale. In comparing height growth of the various species, it should be remembered that rate of juvenile growth is a characteristic that varies considerably among species. For instance, jack pine and the larches normally grow faster during the early years than many other conifers; spruces, on the other hand, normally grow more slowly. Therefore, height should not be the sole criterion in judging the suitability of different species for planting spoil areas. Tree condition and vigor, which help to indicate the adaptability of a species to the site, also are important.

Tables 5 to 7 present more detailed data on survival and height growth in relation to spoil types, acidity of the spoils, and grading. The following discussions of individual species are based largely on data presented in these tables.

Figure 3.—Average survival and height, by species, of trees in all sample plots 7 years after planting. Figures at the bottom of the bars indicate the number of plots studied. For black locust, 7-year data were not obtained; survival shown is based on 12-year-old plantings.

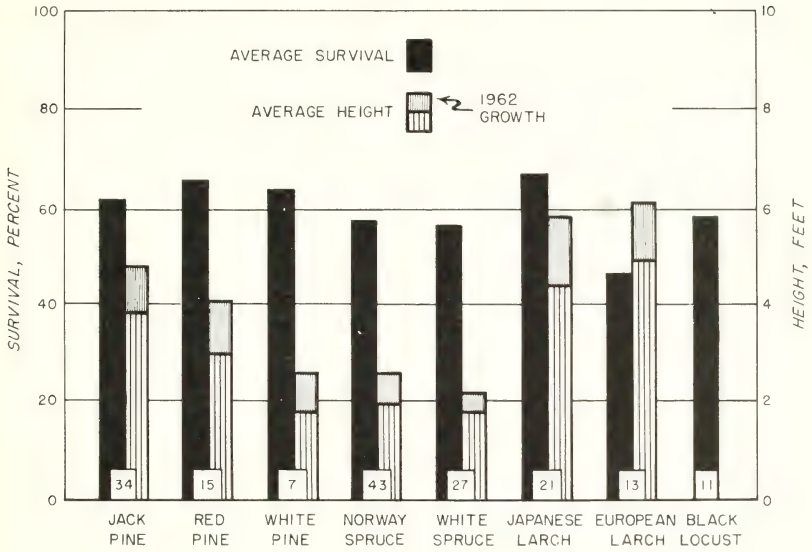

Table 3.—*Survival of 7-year-old plantings, by species*

Species	Average survival	Plots with survival of —				Total
		81 to 100	61 to 80	41 to 60	0 to 40	
	Percent	*— Percent of plots —*				
Jack pine	62	18	38	21	23	100
Red pine	66	20	33	40	7	100
White pine	64	—	29	71	—	100
Virginia pine[1]	60	—	50	50	—	100
Pitch pine[1]	90	100	—	—	—	100
Scotch pine[1]	70	—	100	—	—	100
Norway spruce	58	—	49	23	28	100
White spruce	57	4	26	41	29	100
Japanese larch	68	19	33	48	—	100
European larch	47	—	38	—	62	100
Black locust[2]	59	9	18	64	9	100

[1] Represented by only 1 or 2 plots.

[2] Based on 12 years after planting.

Table 4.—*Height growth and vigor of trees in 7-year-old plantings, by species*

Species	Height			Vigor[1]		1962 height growth	
	Plots	Plot average	Plot range	Plot average	Plot range	Plot average	Plot range
	No.	*Feet*	*Feet*	*Numerical rating*		*Feet*	*Feet*
Jack pine	34	4.8	2.2–8.5	3.1	1.3–4.7	1.0	0.3–1.
Red pine	15	4.1	2.8–4.6	3.1	1.9–3.7	1.1	.6–1.
White pine	7	2.6	.8–4.5	3.7	2.0–4.9	.8	.1–1.
Virginia pine[2]	2	5.7	5.6–5.8	3.0	2.7–3.2	1.1	.8–1.
Pitch pine[2]	2	3.5	3.0–4.0	3.5	3.2–3.7	.7	.6–0.
Scotch pine[2]	1	4.1	——	2.4	——	1.1	——
Norway spruce	43	2.6	1.2–7.6	2.9	1.0–4.2	.6	.2–1.
White spruce	27	2.2	1.1–3.6	3.2	2.7–4.3	.4	.2–1.
Japanese larch	21	5.9	1.0–12.6	3.1	1.5–5.0	1.4	.1–3.
European larch	13	6.2	1.8–10.6	2.6	1.4–4.1	1.2	.3–2.
Black locust[3]	11	30.1	24.2–39.2	—	——	—	——

[1] Rated numerically: 1 = excellent to 5 = very poor.
[2] Data weak because of small number of plots.
[3] Based on the performance of 12 growing seasons.

Table 5.—*Average survival, in percent, and average height, in feet, at 7 years of age as related to spoil type*

Species	Plots	Spoil type								Weighted average	
		I		II		III		IV			
	No.	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*
Jack pine	34	—	—	52	5.1	76	4.3	59	5.0	62	4.
Red pine	15	76	4.4	44	2.6	72	3.9	57	3.9	66	4.
White pine	7	—	—	80	2.3	60	4.5	61	2.2	64	2.
Virginia pine	2	—	—	60	5.7	—	—	—	—	—	5.
Pitch pine	2	—	—	—	—	90	3.5	—	—	—	3.
Scotch pine	1	—	—	70[1]	4.1	—	—	—	—	—	4.
Norway spruce	43	54	2.3	62	3.0	64	1.9	—	—	58	2.
White spruce	27	55	2.1	61	2.5	55	1.9	—	—	57	2.
Japanese larch	21	68	6.0	72	7.7	67	6.1	66	3.0	68	5.
European larch	13	44	8.2	42	5.6	30	2.7	80	7.0	47	6.
Black locust[2]	11	61	30.4	62	32.3	35	24.2	—	—	59	30.

[1] Estimated.
[2] Based on 12 years' growth.

Table 6.—*Average survival, in percent, and average height, in feet, at 7 years as related to acidity classes*

Species	Plots	Acidity classes in pH values														Weighted average	
		3.5–3.9		4.0–4.5		4.6–5.0		5.1–5.5		5.6–6.0		6.1–6.5		6.6–7.4			
	No.	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*
Jack pine	34	—	—	74	4.5	72	5.5	55	5.2	58	4.2	34	4.0	—	—	62	4.8
Red pine	15	—	—	75	4.3	—	—	64	3.9	52	4.4	—	—	44	3.2	66	4.1
White pine	7	—	—	—	—	—	—	64	2.6	60	4.5	60	.8	—	—	64	2.6
Virginia pine	2	—	—	—	—	—	5.6	—	5.7	—	—	—	—	—	—	—	5.7
Pitch pine	2	—	—	—	3.5	50	—	70	—	—	—	—	—	—	—	—	3.5
Scotch pine	1	—	—	—	—	—	—	70[1]	—	—	4.1	—	—	—	—	—	4.1
Norway spruce	43	52	1.7	63	2.5	71	2.7	56	3.2	20[1]	2.3	60	2.4	53	2.4	58	2.6
White spruce	27	66	2.3	57	2.0	62	2.1	49	2.9	—	—	72	1.6	45	2.4	57	2.2
Japanese larch	21	67	8.5	72	6.7	62	5.4	78	3.4	—	—	53	4.7	—	—	68	5.9
European larch	13	—	—	38	5.0	39	6.0	80	7.6	76	8.5	—	—	—	—	47	6.2
Black locust[2]	11	—	—	53	27.4	59	31.3	70	35.8	—	—	—	—	—	—	59	30.6

[1] Estimated value.

[2] Based on 12 years' growth.

Table 7.—*Average survival, in percent, and average height, in feet, at 7 years as related to grading*

Species	Plots	Graded		Ungraded		Weighted average	
	No.	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*
Jack pine	34	63	4.6	64	5.1	62	4.8
Red pine	15	65	4.1	—	—	66	—
White pine	7	63	2.6	—	—	64	—
Virginia pine	2	70	5.7	50	5.6	60	5.7
Pitch pine	2	90	3.5	—	—	—	—
Scotch pine	1	70	4.1	—	—	—	—
Norway spruce	43	54	1.8	59	2.7	58	2.6
White spruce	27	62	1.5	56	2.4	57	2.2
Japanese larch	21	63	2.7	70	7.1	68	5.9
European larch	13	68	5.9	35	6.7	47	6.2
Black locust[1]	11	52	29.1	62	31.3	59	30.1

[1] Based on 12 years' growth.

Jack Pine

Little difference in overall average survival occurred among the pine species that were adequately sampled. However, jack pine plots exhibited the most nearly equal distribution among survival classes from very good to poor (table 3). Survival of jack pine appeared to be affected by spoil type: it was good on type III, but only adequate on types II and IV. No jack pine plots were obtained on type I. Survival seemed to decrease with increased spoil pH within the range from extremely acid to medium acid. Grading had no apparent effect on survival of this species.

For all plots, jack pine averaged 4.8 feet tall. However, heights varied widely among plots. Growth tended to be somewhat better on the more acid spoils (pH 4.6 to 5.0). No definite effects on growth could be attributed to spoil type or to grading, but some trees on lower slopes were as much as 1.5 feet taller than those on upper slopes.

Red Pine

Red pine was the only pine species found on all four spoil types. However, all plots of this species were on graded areas; so no comparison of its performance on graded versus ungraded spoils was possible.

Survival ranged mostly from adequate to very good. It was poor

on only one plot. Both spoil type and acidity seemed to affect survival: types I and III, which were more acid than types II and IV, showed the better survival. The relation of red pine survival to acidity was similar to that of jack pine — best at pH 4.0 to 4.5 and decreasing with higher pH.

Average height for all plots was 4.1 feet. The best growth occurred on spoil type I where survival also was best. However, growth on types III and IV averaged only 0.5 foot less. Growth tended to be poorer with increasing clay content of the spoil and with increasing pH. These trends, although not strongly evident in the tabulated summaries, were indicated by analyses of individual plot data. We can only speculate about the effect of grading; but from general knowledge of the silvics of red pine, we may assume that this species would grow fully as well, and perhaps better, on ungraded areas than on the graded areas where all the plots were found (fig. 4).

Figure 4.—Seven-year-old red pine plantation near Atlas, Pa., on graded spoil type I of pH 3.8 to 4.5. Survival here was 70 percent, average height 4.5 feet.

White Pine

Because only seven plots of white pine were obtained, the data are relatively weak for judging performance of this species under different spoil conditions. Survival was adequate to good on graded spoils of types II, III, and IV (no plots on type I). On type II, where jack and red pines showed their lowest survivals, white pine survival was better than on the other types. All white pine plots fell in the acidity range of pH 5.1 to 6.5; and within this range acidity exerted no appreciable effect on survival.

Average height was 2.6 feet — considerably less than the averages for red and jack pines, and more comparable to the growth of spruces. White pine heights varied a great deal. Growth tended to be better on lower slopes than on upper slopes.

Virginia, Scotch, and Pitch Pines

Each of these species was represented on only one or two plots. Survivals were as good as, or better than, survivals of the other pines. Height growth was somewhat less variable than that of the other pines. Virginia pine growth, which averaged 5.7 feet, was comparable to the best growth of jack pine; similar growth rates by these two species are common also on other kinds of sites. The height growth of Scotch and pitch pines, at 4.1 and 3.5 feet, was comparable to that of red pine. These similarities, too, are common on other sites.

Norway and White Spruces

These two species behaved similarly and therefore can be discussed together. The two species provided 70 plots, but none of these was on spoil type IV. Survival was poor on more than a fourth of the plots. It rated very good on one white spruce plot, and adequate to good on all others.

Survivals did not vary appreciably among spoil types I, II, and III, and they showed no consistent trend in relation to spoil acidity. Differences in survival between graded and ungraded plots were small and probably insignificant.

Average height for Norway spruce was 2.6 feet, and for white spruce 2.2 feet. Slow growth during the early years is normal for spruces; therefore these heights do not necessarily mean that the species are failing. The best growth of both species occurred on spoil type II and at pH 5.1 to 5.5. Growth tended to be less at both higher and lower acidities. Height growth of both species was definitely better on ungraded areas than on graded areas (fig. 5).

Figure 5.—Seven-year-old white spruce plantation in the vicinity of St. Clair, Pa., on ungraded spoil type II of pH 4.6 to 4.8. Average height, 2.0 feet.

Japanese Larch

Japanese larch survived almost equally well on all four spoil types. Survivals ranged from adequate to very good, averaging good for all plots collectively. Survivals were good at all pH levels below 5.5, even in spoils of pH 3.5 to 3.9. At pH 6.1 to 6.5, survival was only adequate. Survival was slightly better on ungraded than on graded areas.

Average height for all plots was 5.9 feet. Best growth occurred on spoil type II (average 7.7 feet), and poorest on type IV (average 3.0 feet). Height growth seemed to be correlated with acidity:

growth was best in the pH range of 3.5 to 4.0 and tended to decrease with decreasing acidity of the spoil. Growth was markedly better on ungraded areas than on graded areas, and on ungraded areas it was substantially better on upper slopes than on lower slopes. This is contrary to the usual effect of slope position.

European Larch

European larch survived less successfully than Japanese larch. Survival was poor on spoil type III, barely adequate on types I and II, and good only on type IV. The overall average survival was adequate (47 percent). All plots fell in the pH range of 4.0 to 6.0; and within this range survival was about twice as high above pH 5.0 as below pH 5.0. European larch seems definitely to be less tolerant of high acidity than the Japanese species. The two species also differed sharply in response to grading: survival of European larch was almost twice as high on graded areas as on ungraded areas, whereas Japanese larch survived slightly better under conditions of no grading.

In height growth, European larch slightly exceeded Japanese larch in the overall averages, and the relationships with spoil type were quite different. The best average European larch growth occurred on type I and the poorest on type III. The different responses to spoil type may be primarily responses to acidity. As table 6 shows, European larch growth increased with increasing pH, whereas the trend in Japanese larch was directly opposite. Despite the much better survival of European larch on graded areas, its growth averaged somewhat better on ungraded areas. The growth of both species was exceedingly variable, even within spoil types and under what appeared to be similar conditions.

PERFORMANCE OF OLDER PLANTINGS

Older plantings (10 to 18 years) are discussed below under two headings, (1) black locust, and (2) conifers. Much more black locust was available for study, and different data were taken than for the older conifers. Except that the locust plots were 0.1 acre in size, the locust data were taken in the same manner as in the 7-year conifer plantings, and are included in the 7-year tables. Because only a few trees of the older conifers were available in many instances, survival data were not taken. The growth and site data for these small groups of trees are presented in table 8.

Table 8.—*Performance of older conifer plantations and associated spoil characteristics*

Species	Age	Trees	Height		Average d.b.h.	Spoil type	Rock content	Textural classification	Acidity	
			Average	Range					Average	Range
	Years	*No.*	*Feet*	*Feet*	*Inches*		*Percent*		*pH*	*pH*
Jack pine	10	7	5.0	3.0–6.5	—	I	80	Sandy loam	3.9	3.7–4.1
	10	6	14.5	13.8–15.6	3.1	I	45	Sandy loam	4.0	3.7–4.2
	11	6	12.8	10.5–14.0	—	II	55	Loam	4.5	4.4–4.5
	11	10	10.4	6.0–14.0	—	IV	30	Sandy loam	5.1	4.7–5.4
Red pine	10	10	12.9	8.2–15.3	2.4	I	75	Sandy loam	4.0	3.6–4.4
	10	8	15.9	10.5–20.4	2.7	II	40	Sandy loam	4.7	4.6–4.7
	12	8	12.8	10.8–15.6	2.3	I	75	Sandy loam	4.9	4.4–5.6
	18	10	17.2	14.2–22.0	4.0	II	60	Sandy loam	3.8	3.7–4.0
White pine	18	10	24.3	20.0–28.0	4.7	II	50	Sandy loam	4.3	4.0–4.5
Virginia pine	10	4	4.6	3.7–5.1	—	III	80	Sandy loam	3.9	3.7–4.1
Pitch pine	11	10	12.6	10.5–14.6	—	I	55	Sandy loam	4.4	4.2–4.7
	11	6	9.3	8.0–11.0	—	II	55	Sandy loam	4.5	4.4–4.5
Scotch pine	10	16	14.1	10.0–19.5	2.2	III	75	Sandy loam	4.4	4.0–5.1
Japanese larch	10	6	17.1	13.6–25.0	3.4	III	55	Sand	4.7	4.5–4.9
	10	6	21.0	17.5–25.8	4.2	I	55	Sandy loam	4.0	3.9–4.1
	13	5	29.2	27.0–33.5	5.3	II	80	Sandy loam	6.7	6.2–7.2
European larch	12	20	22.8	12.5–30.5	3.2	II	45	Sandy loam	5.2	4.8–6.0
	13	10	24.7	17.3–32.0	4.3	II	50	Sandy loam	6.3	6.2–6.5

Black Locust

Most of the black locust plots were on spoil types I and II. Survivals were mostly adequate to good. One plot on spoil type III showed poor survival. Within the pH range of 4.0 to 5.5, which included all the locust plots, survival increased with increasing pH. Survival was slightly better on ungraded areas than on graded areas (fig. 6).

Figure 6.—Fifteen-year-old black locust plantation in Newport Township, Pa., on graded spoil type II of pH 4.4. Survival and growth were sufficient to provide almost complete canopy. A ground cover of herbs and low shrubs commonly developed, as shown here, in the older locust plantings.

Black locust is a notoriously fast grower on mine spoils during its early years. Overall average height on our plots at 12 years was 30.1 feet. Growth was nearly the same on spoil types I and II, but was considerably poorer in the one plot on type III. Growth, like survival, increased with increasing pH. Grading and slope position did not exert much effect.

Conifers

Measurements of 10- to 18-year-old conifers were taken on 158 trees, representing 8 species. Tree age, average height, and diameter by small species groups or plots, and associated spoil characteristics, are shown in table 8. These miscellaneous small samples of trees growing under a diversity of spoil conditions obviously are an inadequate base for firm conclusions, but they do provide some evidence of how forest plantings develop beyond the establishment stage.

Most of the trees were developing normally and exhibited fair to good vigor. There had been no slow-down in growth up to the maximum ages observed. European and Japanese larches were the fastest growing coniferous species and they were growing about equally well (fig. 7). The somewhat poorer growth of the first

Figure 7.—Fifteen-year-old European larch plantation in Hanover Township, Pa., on graded spoil type II of pH 4.9. Survival was 95 percent.

group of Japanese larch (table 8) may be due to the coarse texture of the spoil material.

In general, height and diameter growth of jack, red, pitch, and Scotch pines were comparable (fig. 8 and fig. 9). The distinctly below-average growth of the first group of jack pine and the one group of Virginia pines possibly resulted from the low proportion of soil (particles less than 2 millimeters in diameter) in these particular spoil materials. The one planting of older white pine had made exceptionally good growth — 24.3 feet average height at 18 years. No particular feature of the site to account for this good growth was identified.

Figure 8.—Twelve-year-old Scotch pine plantation in the vicinity of Nanticoke, Pa. on ungraded spoil type III of pH 4.2. Survival was about 40 percent, average height 14 feet.

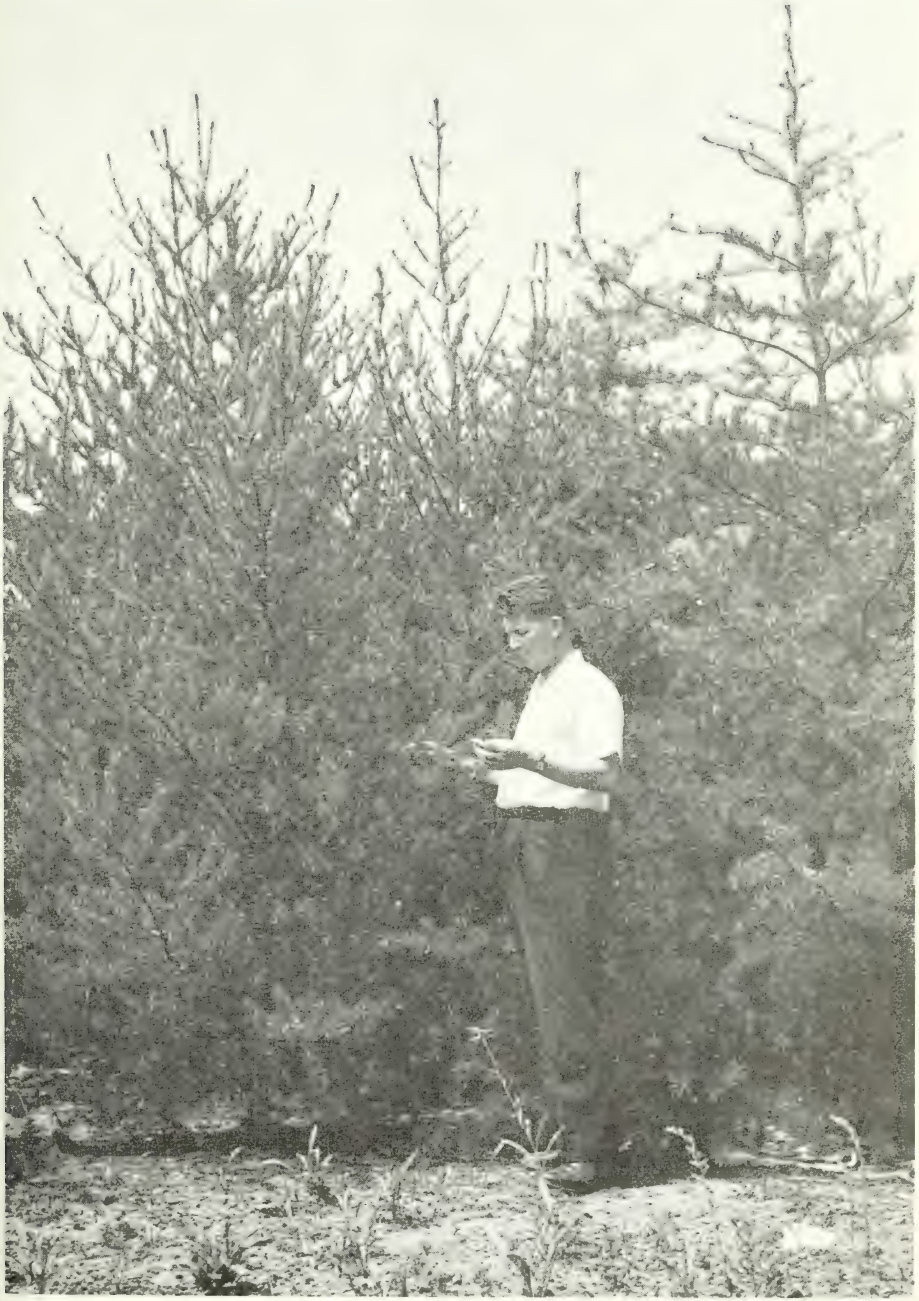

Figure 9.—Ten-year-old jack pine plantation in Wanamie, Pa., on graded spoil type IV.

Table 9.—*Suitability of various sites and conditions on strip-mine spoils for different tree species*[1]

Species	Spoil acidity		Spoil type and grading treatment[2]			Effect of grading on —		Remarks
	Observed range	Apparent optimum	Apparent optimum — Survival	Apparent optimum — Growth	To avoid	Survival	Growth	
	pH	*pH*						
Jack pine	3.8–6.5	4.0–6.0	III–G; IV–G	II; IV	IV–U	Variable	Slightly unfavorable	High mortality due to erosion
Red pine[3]	3.6–8.2	4.0–6.0	I–G; III–G	I; III–G	Heavy tex. spoils	No comparable data		High mortality due to erosion
White pine[3]	3.9–6.8	4.5–6.0	II–G; III–G	III	I–U; IV–U	No comparable data		High mortality due to erosion
Norway spruce	3.5–7.5	4.0–6.0	II–U; III–G	III	I–G; IV–U	Very favorable	Detrimental	Slow early growth
White spruce	3.7–7.8	5.0–6.0	III–G	III	I–G	Slightly favorable	Detrimental	Slow early growth
Japanese larch	3.0–7.0	4.0–5.0	I; II; III	II; III	IV; alkaline spoils	Slightly favorable	Detrimental	Species highly variable
European larch	3.6–7.1	5.0–6.0	II; IV	I–U; II; IV–G	I–G	Slightly favorable	Slightly unfavorable	Species highly variable
Black locust	3.7–6.4	5.0–6.5	II; III	II	Extreme acid I	Slightly favorable	Variable	

[1] Estimates based on both the 7-year and older plantings in this study, and on other plantings observed on mine-spoils throughout the Anthracite Region.

[2] Spoil type shown by Roman numeral; G = graded; U = ungraded.

[3] Species observed only on graded areas.

Discussion and Recommendations

Although this study yielded the most comprehensive and detailed data ever assembled on forest tree plantings as related to strip-mine spoil characteristics in the Anthracite Region, it was nevertheless only a survey of existing plantings that had not been planned and laid out for experimental purposes. Such standard experimental arrangements as replicated plots of each of several species of the same age on each of several specified site conditions simply could not be found. So there are many gaps in the record. Moreover, a number of seeming inconsistencies in tree performance that could not be explained were observed. The causes no doubt lie in obscure differences in the physical and chemical make-up of the spoil material that we did not recognize in this first study.

What we have at this point is a general picture of how plantings of various species on the average strip-mine spoil will develop during the first 7 years, plus some limited evidence on the development of these plantings up to 15 or 20 years of age. We have some ideas about the relative suitability of different spoil types and sites for tree growth, and about the adaptability of different species to these spoil types and sites. But we cannot predict with much precision just how well a given species will grow at a specific location. However, certain generalizations can be made:

- Black locust will provide cover in less time than any other species that has been tried, and it will grow reasonably well on practically all spoils that are capable of supporting any kind of plant growth. Being deciduous, it is not so desirable as evergreens for year-round screen and cover purposes.
- Red pine is the most generally reliable evergreen. It seems capable of surviving and making at least fair growth in practically all situations that will support plants. Jack pine may be considered second to red pine as an evergreen of all-round utility.
- The larches, though adapted to a wide range of spoil sites, are more variable and erratic in performance than red pine,

and they are deciduous. However, they usually will grow considerably faster than red pine. Of the two common species, Japanese larch should be chosen for the more acid sites and European larch for the mildly acid to neutral sites.

The spruces will survive adequately in most situations, but their early growth is slower than that of most other species, and their capacity for good growth later remains to be demonstrated. The spruces would be a poor choice where the time required to attain a given size is important.

A major objective of this study was to prepare a preliminary planting guide for use in tree planting projects in the Pennsylvania Anthracite Region. But because of the deficiencies in our data, a true guide — one that would specify particular species for particular site situations and conditions — cannot be prepared as yet. However, we do have a number of useful observations on the suitability of various site situations for different species. These observations are given in table 9. Although the table is based primarily on the study plots, observations on other plantings on mine spoils also were considered. The table is designed mainly to identify, for each species, the situations that seem to be distinctly more favorable, and those that are distinctly less favorable than the average run of mine spoil sites. Situations that are not named can be assumed to be suitable — neither particularly good nor particularly bad — for the species under consideration. Table 9, in conjunction with the preceding general statements on black locust, red and jack pines, larches, and spruces, should serve as a tentative planting guide until better information becomes available.

Another of the listed objectives of this study was to identify the gaps in our knowledge of ways to revegetate strip-mine spoils and suggest problems most in need of further research. The survey results have clearly demonstrated that several tree species will survive and grow reasonably well on many spoil sites. But the survey also has clearly demonstrated that we do not have really reliable information about comparative performance of the different species on the same sites, or about what are the most influential site factors. A properly designed planting experiment to provide reliable comparative data on the performance of different species on different site situations seemed clearly to rank high in priority, and such an experiment was begun in the spring of 1963.

Summary

A survey type of study was conducted in 1962 and in 1963 to evaluate the performance of existing forest-tree plantings of several species on strip-mine spoils of the Anthracite Region. The spoils were classified into four types based on the predominant parent material. Tree measurements 7 years after planting, together with pH and certain physical characteristics of the spoil, were obtained from 198 sample plots. All known plantations of suitable age throughout all four anthracite coal fields were sampled. From the results of the study the following generalizations may be stated:

- Overall average survival of all species was adequate (in the range of 40 to 60 percent), provided no disturbance had occurred after planting.
- Height growth of trees planted on the spoils was generally comparable to growth on natural soils of average productivity. Red pine, for instance, averaged 4.1 feet tall 7 years after planting, and the larches averaged 5 to 6 feet.
- No extensive conditions that would preclude tree growth were observed. The performance of existing plantings indicates that a tree cover of some sort can be re-established on practically all anthracite strip-mine spoil areas.
- Survival and growth of most of the species studied varied with such site characteristics as spoil type, soil texture, pH, grading history, and slope position. The trend and the magnitude of the effects of these factors differed somewhat among species, but we do not now have suitable data to define the precise relationships.

A preliminary guide for forest tree planting on anthracite spoils has been prepared on the basis of the present data. It is weak in many respects, and will require refinement by further research before species can be recommended for different mine-spoil sites with assurance of optimum survival and growth.

A high-priority research need is to determine the comparative

performance of different tree species on different mine-spoil sites. This will require properly designed experimental plantings. Research of this sort was begun in the spring of 1963.

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by Alex L. Shigo

DECAY and DISCOLORATION following logging wounds on northern hardwoods

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DECAY *and* DISCOLORATION

following logging wounds on northern hardwoods

■

Attention to Quality

GROWING high-quality timber is one purpose of all forest managers. More and more attention has been paid to quality in recent years. And as emphasis on quality has increased, forest managers have felt a need for more information about any management activity that affects the quality of individual trees.

What can happen to a tree that will affect its quality? Logging, for one thing. The trend in logging today is toward bigger machines and fewer men, and toward shorter intervals between timber harvests. This leads to greater productivity, but it brings with it new problems. One is the increase of logging damage to the trees that are left.

This trend toward more serious logging damage was recognized by Fobes (1958), who listed 79 studies on this subject. He considered as logging damage any disturbance by logging that reduced the capacity of the area to produce a desirable future crop. He classed damage as either *primary* — immediately after logging;

or *secondary* — years after logging. Most of the studies that Fobes cited were concerned mainly with machines, methods, and above-ground damage. Olson (1952) pointed out the importance of injury to roots by heavy equipment.

Even though diseases that follow logging injuries are principal causes for low quality among trees, only a few studies have dealt with the pathology of logging wounds. Decay associated with logging wounds has been studied in the West on conifers (Parker and Johnson 1960; Wright *et al.* 1947; Wright and Isaac 1956) and in the Lake States on sugar maple and yellow birch (Hesterberg 1957; Benzie *et al.* 1963). In the South, where fire is the major cause of wounds, decay studies have concentrated on fire scars as infection courts (Hepting 1935 and 1941; Toole 1959). Because decay is the most important defect of trees in the South and West, little attention has been given to other defects — including discolorations.

In northern hardwoods — unlike most other hardwoods — the white wood is usually the most valuable part. For these species — beech, birch, and maple — discolorations are often as degrading as decays. The few studies on logging wounds of these northern hardwoods have dealt primarily with decay and have given only slight attention to discoloration (Hesterberg 1957; Benzie *et al.* 1963). A few studies have been made of the discoloration that follows wounding by increment borers (Hepting *et al.* 1949; Campbell 1939; Lorenz 1944). These studies revealed that discoloration formed much more rapidly in northern hardwoods than in other species studied. Most of the research on discoloration has been done by pathologists studying wood products (Scheffer and Lindgren 1940).

Although the importance of fungi in decay processes cannot be disputed (Boyce 1961), the same cannot be said for discoloration processes in living trees. Thus, while Lorenz (1944) indicated that micro-organisms were not important in discoloring processes, Good and Nelson (1951) stated that most discolorations in maple were caused by fungi. Possibly both views are partially correct, for while beginning stages may not involve organisms, later phases certainly do (Shigo 1965a). The effects on discoloration of

changes in moisture and air following tissue injury have been investigated (Zycha 1948).

In addition to the action of fungi and of changes in air and moisture, other factors, including the action of bacteria, must also be considered (Shigo 1963). Although wood-inhabiting bacteria have been studied in some trees (Hartley *et al.* 1961), their possible role in decay and discoloration processes has been suggested only recently (Shigo 1963). The close association of bacteria, non-Hymenomycetes, and Hymenomycetes in living trees has been pointed out (Good and Nelson 1962; Shigo 1963).

Because these different organisms are associated commonly in living northern hardwood trees, each must be included in a study of the destructive processes that follow wounding. The purposes of this paper are to report and discuss results of studies on decay and discoloration in northern hardwoods following logging wounds.

Materials and Methods

From 1959 to 1964, 331 northern hardwood trees (sugar maple, *Acer saccharum* Marsh.; red maple, *A. rubrum* L.; yellow birch, *Betula alleghaniensis* Britt.; paper birch, *B. papyrifera* Marsh.; American beech, *Fagus grandifolia* Ehrh.; and white ash, *Fraxinus americana* L.) growing on the White Mountain National Forest in New Hampshire were felled, dissected, and studied. The trees ranged from 6 to 26 inches in diameter at breast height (d.b.h.) and bore logging wounds inflicted 2 to 60 years previously. Logging records and old skid trails and landings aided in locating wounded trees.

Before a tree was cut, the following data were recorded: date; tree number; tree species; location; notes on site; vigor; d.b.h.; crown class; notes on injuries to roots and branches; the number, position, and condition of branch stubs; seams and open cracks; fungi fruiting on the wound surface and elsewhere on the tree; number and position of wounds; greatest length and width of wound; severity of wound (1. bark scraped, 2. wood scraped, 3. wood broken to depth of 0.5 inches, and 4. wood broken to a

depth of over 0.5 inch); healing rate; circumference of tree at wound; percentage of circumference wounded; cause of wound (skidding, felling); and general remarks (insects in tree and in wound face, sapsucker injury, porcupine injury).

The tree was then felled with a chainsaw and dissected longitudinally through the pith as described by Shigo (1964).

Immediately after dissection the following data were recorded: extent of decay and discoloration above and below the wound; volume of decay and discoloration (greatest length, width, and breadth); notes on type of decay and discoloration; age of wound and tree; when present, measurements of the central dark column throughout the tree; merchantable height; notes on branch stubs, other defects, insect injury, and the like.

On some trees, relative moisture content of the clear wood, discolored wood, and decay were taken with a moisture meter (Delmhorst Model RC-1, not accurate above fiber-saturation point). The Truog pH indicator (Hartley *et al.* 1961) was used to measure pH gradients across decayed, discolored, and clear wood.

The wood samples taken for isolation of organisms were approximately 12 x 6 x 4 inches and contained clear wood as well as defects. At least four samples were collected from the immediate wound area and from regions above and below the wound.

In the laboratory, samples were washed in 0.5-percent sodium hypochlorite (Clorox) solutions: 10 minutes in one bucket, and the same time in a second bucket. The samples were then split open with a flamed axe. Small chips of wood were removed aseptically with a gouge from numerous spots on the exposed inner surfaces and placed in an agar medium in petri dishes. A 2-percent agar medium containing 10 g malt extract and 2 g yeast extract per liter of distilled water was used. A total of 34,735 chips were examined.

Assistance in identifying micro-organisms was given by bacteriologists at the University of Connecticut, and by mycologists at the Forest Service Disease Laboratory in Laurel, Md. (Hymenomycetes). Species of *Phialophora* were identified by C. J. K. Wang, N. Y. State University College of Forestry at Syracuse; and S. J. Hughes, Department of Agriculture, Ottawa, Canada.

Results

Observations in Logged Areas

Observations of areas logged 1 month to 60 years previously indicated that many of the injuries had been apparent at the time of logging but had almost disappeared within a few years.

The shallow and often exposed roots of yellow and paper birch trees were especially vulnerable to injury (fig. 1). The bases of trees bordering bends in trails were injured repeatedly (fig. 2). Trees with such root and basal injuries often died within a few years (fig. 2). Living but weakened trees were attacked by many weakly parasitic organisms and insects, and were thus rendered even more defective. Root and bole injuries, coupled with changes in stand environment resulting from logging, were enough to seriously weaken and sometimes kill trees. This type of after-logging decadence was common (figs. 2 and 3).

The number of injured trees present varied from one logged area to another. Half of one area studied had few injured trees,

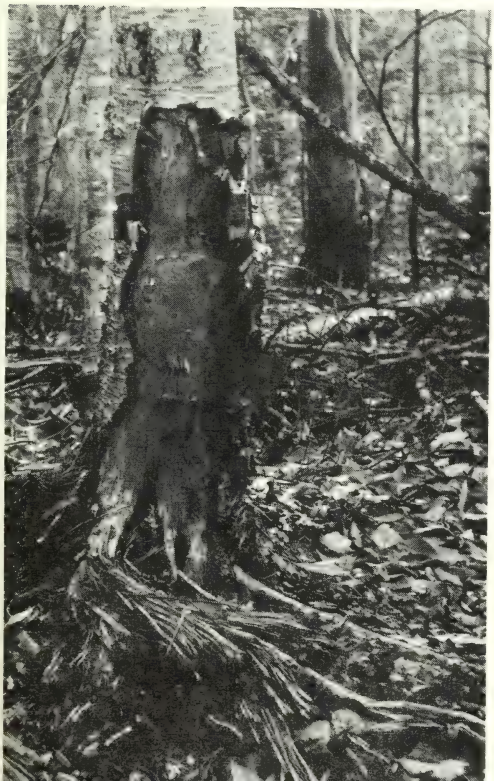

Figure 1.—Root and basal injury to a yellow birch tree bordering a skid trail. A common type of logging wound.

Figure 2.—Injuries on sugar maples bordering a bend on a skid trail. The tree on the right died 8 years after the roots and bole were injured.

Figure 3.—Felling injuries on two yellow birch trees. The tree on the right died and was invaded by decay fungi within 8 years after injury.

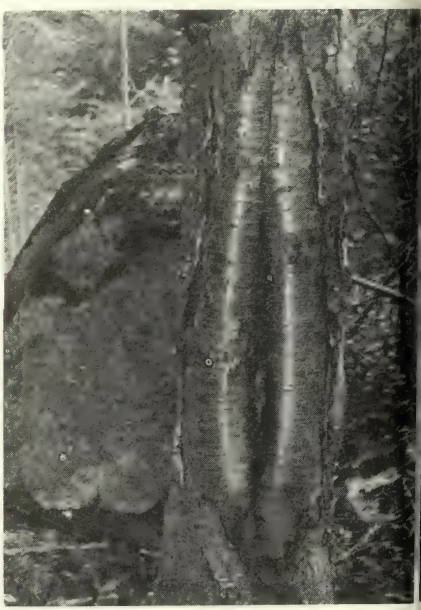

Figure 4.—A 60-year-old wound on a yellow birch tree 160 years old and 26 inches in diameter (d.b.h.). Sporophores of *Fomes igniarius* var. *laevigatus* are on the wound face.

Figure 5.—Dissection of the first 8-foot bolt of the tree shown in figure 4. Decay and discoloration was limited to the wood tissues present when the tree was wounded. More wood formed on the side of the tree opposite the wound. On the wound side, a dark discoloration in the annual ring that formed when the tree was wounded was the boundary between tissues formed before and after wounding. The discoloration extended far above the wound.

while the other half had many, even though topography and stand composition were similar. The local forest ranger said that although logs from both areas were skidded with tractors, two operators were involved and one was more careless than the other.

Dissection of Injured Trees

As the longitudinal dissections (figs. 4 and 5) exposed internal tissues to air, various changes occurred in the wood. The columns of discolored wood enlarged as liquids oozed from cut ends; and the colors of both clear and discolored wood changed, becoming darker in some areas with wetting and lighter in others with drying. In maples, the common black–green discoloration often intensified around the edges. Zone lines, vivid at first, faded upon exposure. In birch, moist dark-pink to tan margins of discoloration surrounding decay dried more slowly than other tissues and often became hard and white. Mottling resulted when moist pockets remained in the discolored zones.

In pH, clear and decayed wood were similar (4.5 to 5.5), while pH of discolored wood varied from 5.0 to 8.5. The highest pH readings were obtained from the narrow zones of moist discoloration immediately surrounding decay. The moisture content of these discolored tissues was higher than that of the clear wood.

The Wound

The appearance of the wound face was the best indicator of the extent of internal defects. Dark wound faces indicated more defect than light ones (figs. 6, 7, 8, and 9). The dark color was due to decaying wood, minute fungus fruiting bodies, dark mycelium and spores, and bits of soil and debris. Dark faces usually occurred on wounds that had deep cuts (figs. 6 and 7) and on wounds that had been shaded from the sun.

Dry, white-faced wounds indicated little decay and discoloration, even if large and old (figs. 8 and 9). Such wound faces usually formed when wounds were exposed to sunlight or did not penetrate the wood deeply. In one location (logged 13 years previously), several red maple trees had white-faced wounds. The callus tissue around the wounds of some of these supported perithecia of *Nectria galligena* Bres. Dull tan-colored stains occurred

Figure 6.—An 8-year-old wound on yellow birch 106Y. The wound face was dark and had deep cuts in it. Sporophores of *Polyporus versicolor* were abundant on the wound.

Figure 7.—Dissection of yellow birch 106Y. Decay and discoloration from the wound and from branch stubs joined. The dark core in the upper bolt was limited to tissues formed when the branches died.

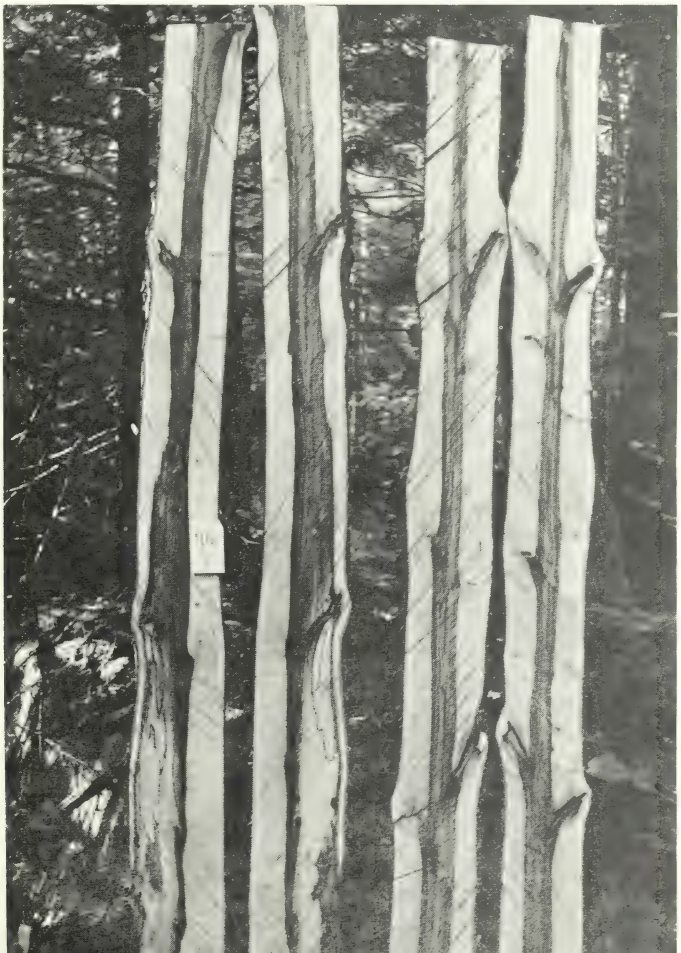

Figure 8.—A white-faced wound on a sugar maple. Dark tan stains are on the wound face.

Figure 9.—Dissection of the tree shown in figure 8. Very little decay and discoloration was associated with the wound.

on many white-faced wounds (fig. 8). Other factors, including insects, affected the decay and discoloration that developed behind wounds.

When insects bored in wounds, the discoloration or decay advanced at least to the depth of the holes. Insects commonly infested new wounds within a year, and attack continued until hundreds of holes were bored in some wounds. Ants commonly infested wounds on beech, but usually confined their activities to areas already discolored or decayed.

Birches particularly were infested by ambrosia beetles after the trees had been weakened by severe wounding. Insect attacks resulted in several different internal patterns. A U-shaped pattern revealed that some beetles attacked trees and then left them within a short period during the year of wounding (fig. 10). When the trees were attacked a year or more after wounding, the ambrosia

Figure 10.—Cross-sections of a yellow birch at 4 and 16 feet above the basal wound. The U-shaped discolorations were caused by insects that attacked the tree after it was wounded. All the tissues present when the tree was wounded by thousands of insects all around the bole were discolored slightly pink, but no organisms were associated with the slight discoloration. The wedge-shaped column of discoloration and decay advancing from the logging wound joined the central column of discoloration. Organisms were associated with these defects.

beetles bored approximately ¼ to 1 inch straight into the trees. These holes resembled many minute increment-borer wounds. The discoloration patterns around holes were similar to those around increment-borer wounds (Hepting *et al.* 1949). Small discrete areas of discoloration often coalesced to form larger ones, with ends pointed outward toward the cambium (fig. 11).

Several sugar maple trees had been attacked by the sugar maple borer, *Glycobius speciosus* (Say), the same year they were wounded during logging (figs. 12 and 13). This may have been an indirect effect of logging rather than wounding, because these beetles often attack trees in opened stands.

Figure 11.—Ambrosia beetles attacked this paper birch after it was wounded at the base. The tissues formed after the insects attacked were not discolored. The discolorations from the insect wounds coalesced with each other and with the central discolored column in the tree. Organisms were associated with the discolorations.

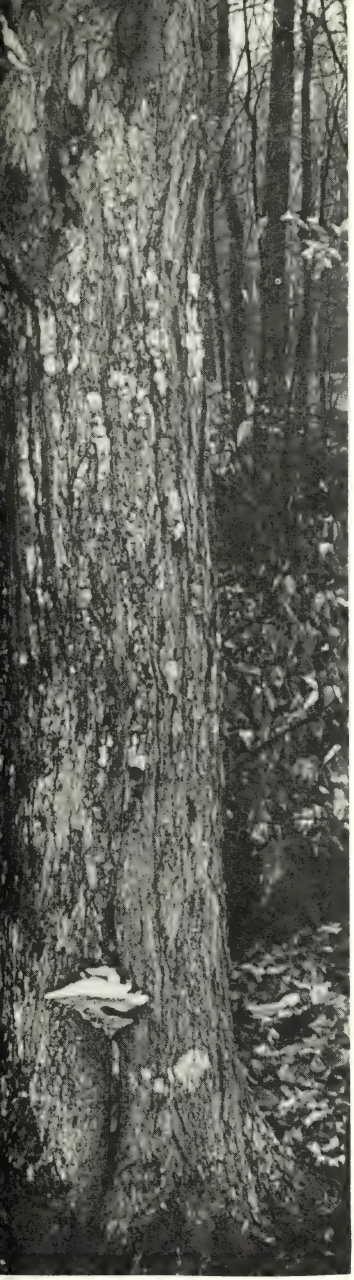

Figure 12. — The basal wound on this sugar maple bears a spohophore of *Fomes connatus*. The large wound above was caused by a sugar maple borer.

Figure 13.—Dissection of the tree shown in figure 12. The sugar maple borer attacked the same year the tree was wounded. Tissues formed after both wounds were inflicted remained clear. Discolored wood that yielded bacteria and non-Hymenomycetes surrounded the decay column.

Cracks formed on some trees above and below logging wounds. This was most noticeable on paper birch trees because such cracks and wounds turned rough and dark in contrast to the thin white bark (fig. 14). These cracks increased greatly the defects associated with wounds. Callus tissue that developed around such cracks and wounds was less extensive in beech than in other species.

In beech, several factors influenced the effects of wounds. One was the beech bark disease. The beech scale, *Cryptococcus fagi* (Baer.), infested wound callus tissues and *Nectria* spp. infected through the insect wounds. To complicate this further, another scale insect, tentatively identified as *Xylococculus betulae* (Perg.) Morrison, often attacked callus tissues too. These organisms made it difficult to assess the severity of the original wound.

Beech differed from other species in that its root collar was highly resistant to decay. Internal defects usually were constricted

Figure 14.—Cracks formed above and below the wound on this paper birch. The bark became rough and dark around the cracks. This was not the result of mechanical bark stripping that is common along roadsides.

Figure 15.—The column of defect in this beech tree narrowed abruptly as it approached the base, but the column was large above the wound as it joined the central column formed after branches died.

abruptly near the root collar (fig. 15). Two common exceptions were basal wounds infected by *Fomes applanatus* (Pers. ex Wallr.) Gill. and *Polyporus versicolor* L. ex Fr. These fungi were aggressive invaders of butts and roots.

The sides of trees above and below old wounds usually were flattened. The extent of these areas depended on the size, age, and severity of the wounds. Internal defects associated with wounds usually were confined to the wounded sides of trees (fig. 16).

Patterns of Decay and Discoloration

The amounts and types of decay and discoloration within nearby trees of the same species having similar wounds often differed markedly (figs. 17 and 18). Extensive decay and discoloration was associated with wounds on trees that already had defective

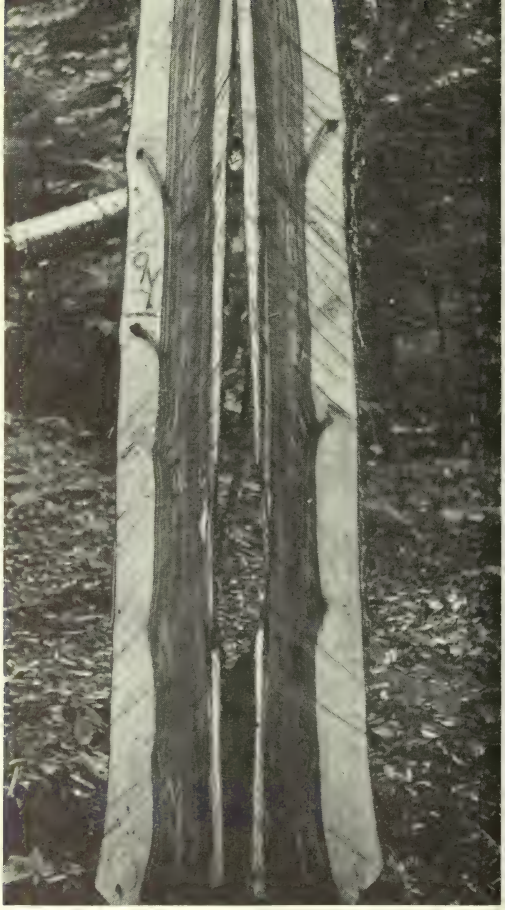

Figure 16.—This yellow birch was wounded 3 feet above the base, and the discoloration that followed was wedge-shaped and confined to the side of the tree that was wounded. Organisms were associated with the discoloration.

centers, and especially when such previously formed defects were associated with branch stubs. On the other hand, little additional defect developed if the wounded trees had but little previous defect (fig. 18). Decay and discoloration initiated at logging wounds appeared to spread toward similar defects already present in the trees. Thus the presence of prior defects apparently influenced the rate of formation of additional defects from logging wounds.

It was often difficult to separate the effects of logging wounds from those of branch stubs when both injuries occurred on the same tree (fig. 7). This was true especially of older wounds on older trees. Because decay followed discoloration and advanced more slowly, separate decay columns that once were isolated did not coalesce as readily as did separate discoloration columns.

With few exceptions, *tissues formed in the years after trees were wounded did not become discolored or decayed* (figs. 5, 13, and 19). While this means that the maximum diameter of discolored cores was limited by the diameter of the tree when its branches died or when wounds were inflicted, it does not mean that *all* tissues present when wounds were inflicted ultimately would be discolored or decayed. On the contrary, the extent to which such tissues were affected was determined principally by wound age, severity, and size.

For example, the presence of several large, severe wounds about the base of a tree usually indicated the presence of circular central cores of defect (figs. 5, 13, and 19). Yet, if these were large white-faced wounds, little defect was associated with them and no circular defect core developed (fig. 9). But upon close examination of even these wounds with relatively little associated defect, a faint discoloration column was noticeable for several feet above and below the wound in all wood tissues present when the wounds were inflicted. These tissues yielded no organisms. In birches and maples a slight pink discoloration was common that faded quickly after dissection and was difficult to see a few hours later. The annual ring formed the year of wounding became darkened, and this served to indicate the date of wounding (fig. 5).

In radial sections the most common shape of discoloration was a wedge with its point near the pith (fig. 10). This configuration, common in wounded trees that had little or no other previous internal defects, affected more tissues than did the thin bands associated with white-faced wounds (fig. 9), and less tissues than did the continuous central columns associated with severe wounds (fig. 19). But, if internal defects were present when trees were wounded, shapes of defect columns varied. For example, thin bands of discoloration behind white-faced wounds often joined the other defects to form jagged patterns, and wedge-shaped defects formed blunt-shaped defects as they joined central columns (fig. 10).

The upper ends of most decay columns in all species examined ended abruptly. Even extensive columns often had rounded tops (fig. 18). A few short sections of hollowed centers were seen in trees wounded severely on opposite sides (fig. 19).

Figure 17.—Two sugar maple trees approximately the same size and age, both with similar 8-year-old wounds.

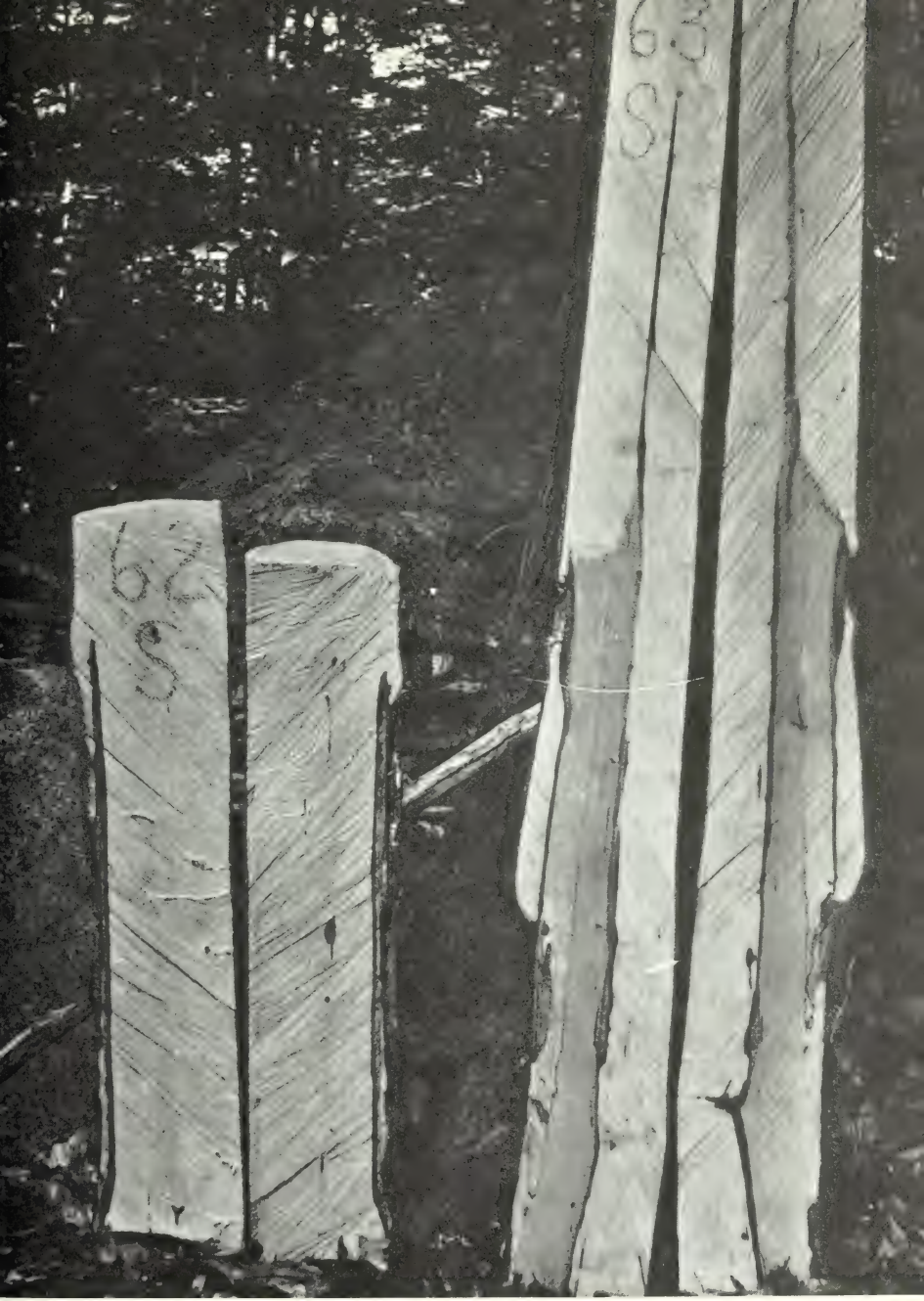

Figure 18.—Dissection of trees shown in figure 17. The tree on the left had very little defect associated with the wound, while the other tree had extensive decay. Tree 62S had few defects in it when it was wounded, while 63S had defects in it from a low branch stub. The decay ended adruptly above the wound in 63S.

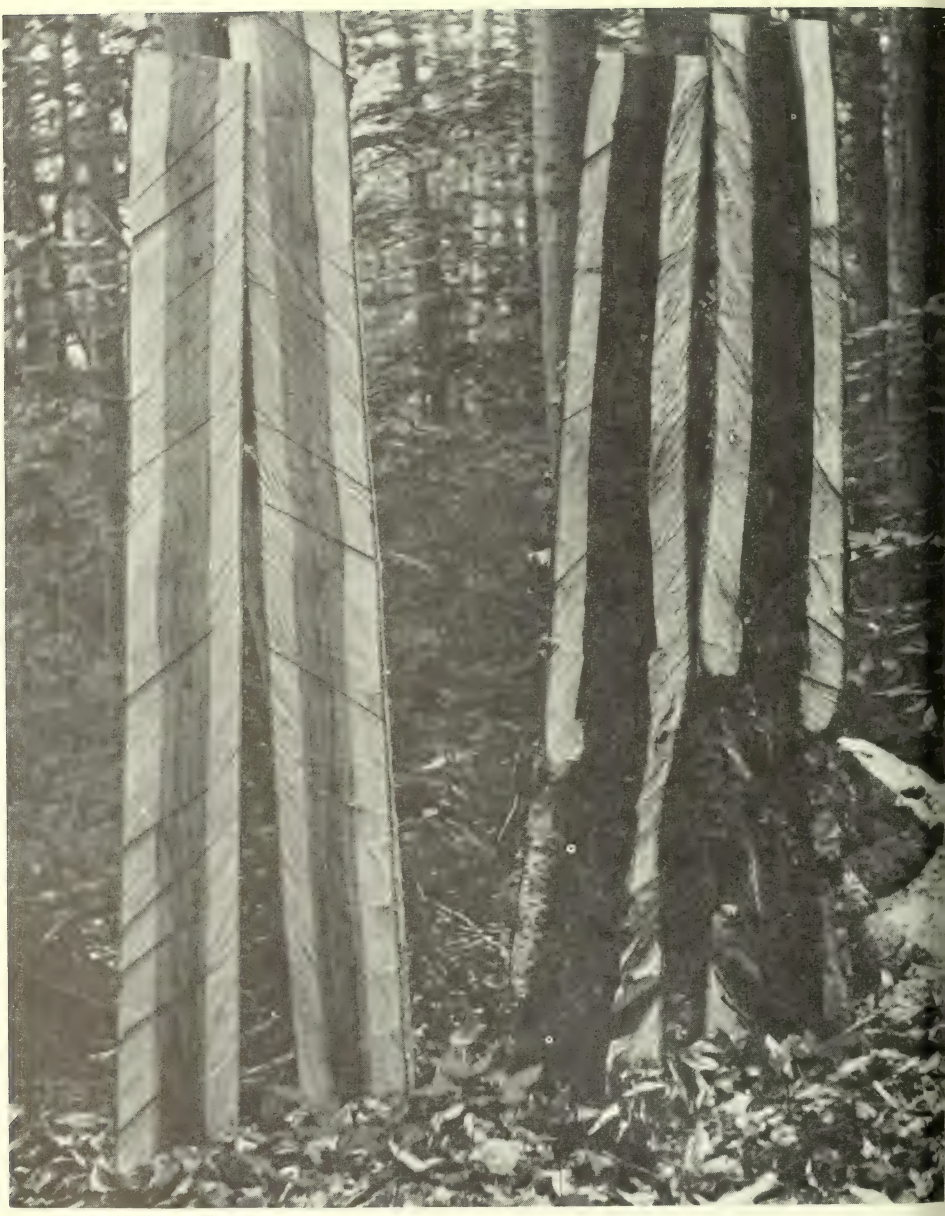

Figure 19.—Two 50-year-old wounds on opposite sides of the base on a 100-year-old paper birch. The tissues present when the wounds were inflicted were digested completely in the first 8-foot section. The decay advanced through the discoloration and the discoloration was limited to those tissues formed when the tree was wounded.

Most defects already present had advanced from branch stubs (fig. 7). Dark discolored cores in many trees were caused by processes initiated when branches died (fig. 7). Discolored cores in northern hardwoods did not form independent of branch stubs or other wounds, and unwounded trees that bore no large branch stubs had white wood throughout (fig. 18).

When wounds occurred or when branches died at about the same time, the resultant discolored core was contained within the tissues bordered by the same growth ring (figs. 5 and 13). But when such events occurred at different times, discoloration and decay from different defects coalesced to form defect columns with uneven margins.

Several decay fungi disrupted the usual pattern of decay and discoloration. Once established in birches, *Poria obliqua* (Pers.) Bres. became weakly parasitic and invaded tissues that formed around the infection court. *Fomes igniarius* (L. ex Fries) Kickx sometimes invaded similar tissues on beech and sometimes on maples. Fungi growing into roots from basal wounds also disrupted the usual defect pattern in the stem.

Organisms Associated with Decay and Discoloration

Fruiting bodies of fungi, especially non-Hymenomycetes, were common on wound faces. The most common fungus to fruit on wound faces 3 years old or older was *Hypoxylon rubiginosum* Pers. ex Fries (fig. 20). The *Acrostaphylus* imperfect stages of five *Hypoxylon* spp. were isolated from discoloration and decay associated with wounds. Again the most common species was *H. rubiginosum.* It was isolated from tissues discolored red–brown and from white pockets of decay in all species. Stromata were often near fruiting bodies of other fungi on wound faces, especially those of *Stereum complicatum* (Fr.) Fr. and *Polyporus versicolor.* These Basidiomycetes formed fruiting bodies readily on wounds that were less than 10 years old (fig. 6). *H. rubiginosum* frequently was isolated together with bacteria, but this association was not so common with *H. rubiginosum* as it was with some other non-Hymenomycetes. Many stromata were scraped and scratched as if insects had attempted to eat them.

Figure 20.—Stromata of *Hypoxylon rubiginosum* on a basal wound on a beech tree. Both globose and effused forms are present.

Another member of the Xylariaceae, *Daldinia concentrica* (Bolt. ex Fr.) Ces. and deN., formed stromata on wound faces and frequently in crevices formed in the callus tissues around the edges of wounds. Decay and discoloration caused by this fungus were similar to those caused by *H. rubiginosum.* Stromata formed most frequently on sugar maple and yellow birch wounds that were over 4 years old. It was an aggressive early invader of wounds and of dead stems and branches, especially those of yellow birch. In the laboratory, stromata formed on debarked, unautoclaved small stems of red maple in jars. No perithecia formed, but the imperfect *Acrostaphylus* stage produced an abundance of spores on the wood.

Stromata of *Hypoxylon deustum* (Hoffm. ex Fr.) Grev. (*Ustilina vulgaris* Tul.) seldom were seen on basal wounds, and the fungus was cultured but rarely from wounds on sugar maple. The fungus caused a decay similar to that caused by *Daldinia* and other species of *Hypoxylon.*

Phialophora spp. were not found fruiting on the wound faces, yet these fungi were the principal ones isolated from discolorations in all species (table 1). The fungi were isolated commonly from discolored tissues that usually were very moist, ranged in color from light tan to black–green, and had a pH as high as 8.5. *Phialophora* spp. were cultured frequently from the pith and from discolored tissues surrounding the pith, and they produced spores in pith cells and in vessels of discolored wood in living trees (fig. 21). Although these fungi were some of the first to invade the wounds, they also were isolated frequently from discolorations surrounding decay that had advanced from wounds inflicted over 50 years ago.

The principal *Phialophora* was *P. melinii* (Nannfeldt) Conant. This species closely resembles *P. fastigiata* (Lagerberg and Melin) Conant (van Beyma 1943). Frequently the fungus was associated intimately with bacteria in the wood, and in culture these organisms grew well together.

Phialophora lignicola (Nannfeldt) Goidanich was not isolated as frequently as *P. melinii,* but it also was associated intimately with bacteria.

Other unidentified species of *Phialophora* were isolated, but they were not so abundant as the above-mentioned species. Fungi identified as *Margarinomyces* are probably species of *Phialophora.*

At least two species of *Phialocephala* were isolated: *P. bactrospora* Kendrick and a species close to *P. dimorphospora* Kendrick (Kendrick 1961). Most of these fungi were isolated from discolorations associated with wounds on yellow birch.

Trichocladium canadense Hughes (Hughes 1959) was the fungus isolated most frequently from the light tan to deep brown discoloration in maples and beech, and especially the red–brown discoloration in birches, and from moist tissues with a high pH (table 1). The fungus was isolated frequently along with bacteria.

Table 1.—*Numbers of trees yielding organisms*

Trees	Beech	Sugar maple	Red maple	Paper birch	Yellow birch	White ash
Total trees	82	48	29	46	116	10
Bacteria	53	33	23	40	97	8
Non-Hymenomycetes	72	45	29	41	115	8
Phialophora spp.	52	29	21	27	68	6
Trichocladium canadense	38	12	13	32	77	1
Hypoxylon spp.	34	13	9	7	33	7
Libertella sp.	4	5	3	4	9	0
Nectria spp.	12	8	5	5	17	0
Daldinia concentrica	1	4	0	1	7	0
Coryne sp.	4	2	1	2	7	0
Graphium sp.	3	2	1	2	7	0
Cytospora decipiens	0	0	6	0	0	0
Mucor spp.	6	1	0	0	2	0
Cladosporium sp.	0	1	0	0	0	0
Cephalosporium sp.	1	3	1	0	1	0
Verticillium sp.	0	1	1	0	0	0
Ceratocystis sp.	1	1	0	0	2	0
Hymenomycetes	62	32	20	32	98	8
Pholiota squarrosa-adiposa	5	0	0	8	20	0
Poria obliqua	0	0	0	8	8	0
Stereum pupureum	0	0	0	1	5	0
Tricholoma unifactum	1	0	0	1	3	0
Polyporus versicolor	1	2	0	0	7	1
Fomes igniarius	4	0	2	0	1	0
Fomes connatus	0	4	2	0	0	0
Fomes applanatus	3	0	0	0	0	0
Trechispora raduloides	2	0	0	0	1	0
Hericium sp.	6	0	0	0	0	0
Corticium vellereum	1	1	1	0	0	0
Armillaria mellea	2	1	0	0	1	0
Polyporus tulipifera	1	2	0	0	4	0
Polyporus adustus	0	1	0	1	0	0
Polyporus ostreatus	1	0	0	0	0	0
Polyporus glomeratus	0	0	1	0	0	0
Stereum murrayi	0	0	0	1	1	0
Poria cocos	0	0	0	0	1	0
Lenzites betulinus	0	1	0	0	0	0
Unidentified Basidiomycetes	25	15	13	1	22	7

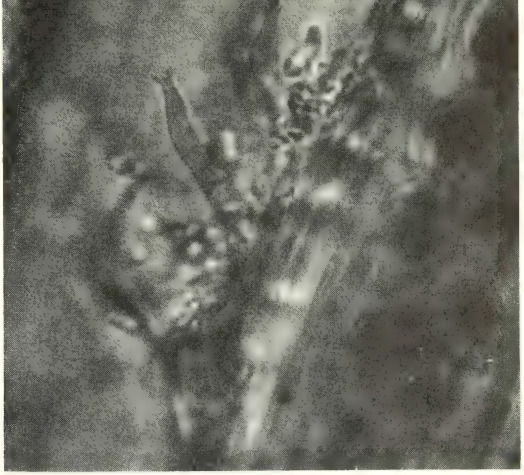

Figure 21.—Phialophores of *Phialophora* sp. producing spores in a vessel in discolored wood in a living tree.

These organisms grew very slowly together in culture. Faster-growing fungi often overgrew *T. canadense,* but its presence could be detected by the black mycelium that grew to the bottom of the petri dish.

Many other fungi were isolated from discolorations (table 1), but none so frequently as those mentioned above. *Nectria* spp. were isolated occasionally from beech and yellow birch, but not consistently even from wounds bearing *Nectria* perithecia on in-rolled callus. Therefore, they may have been more abundant than indicated by isolations. A species of *Libertella,* isolated occasionally from all species, resembled the imperfect stage of the well-known canker fungus *Eutypella parasitica* Davidson and Lorenz. Fungi not listed in table 1, but which were isolated a few times, were members of the following genera: *Gliocladium, Fusarium, Phomopsis, Penicillium, Sphaeropsis, Sporotrichum, Leptographium, Chaetomium, Chloridium, Mortierella, Streptomyces,* and *Trichoderma.*

As with the non-Hymenomycetes, many species of decay fungi were isolated, but relatively few were isolated frequently. Many fungi, comprising a large share of the isolations, were isolated only a few times and were not identified.

Pholiota squarrosa-adiposa Lang[1] was the principal fungus isolated from decay in birches and beech. In culture small fruiting

[1] Identified by Dr. Orson K. Miller, Jr., U.S. Forest Service Forest Disease Laboratory, Laurel, Maryland.

bodies that produced spores often formed after 3 weeks. Ephemeral sporophores formed on trees in early fall.

Poria obliqua was isolated from paper birch as frequently as *Pholiota squarrosa-adiposa* (table 1). The large, black, sterile masses of fungus material were found on many old wounds from which a brown liquid oozed. Decay in such trees was moist and had a foul odor, and the discoloration around it abounded with bacteria.

Fomes applanatus caused decay in bases and roots of beech. *Hericium* spp. were isolated only from beech and sporophores formed on old wounds. Other decay fungi isolated from wounds are listed in table 1.

Bacteria were isolated frequently from decayed and discolored tissues. Isolation results revealed that although bacteria were the first organisms to infect new wounds, they were present also in the oldest wounds. They grew alone and in close association with fungi. In culture they grew rapidly and sometimes retarded the growth of the fungi. In many such instances the only indications that fungi were present were small tufts of mycelium growing from tops of isolation chips. Possibly bacteria may have inhibited completely the growth of some fungi.

To determine the identity of the principal bacteria associated with decay and discoloration in northern hardwoods, a cooperative study was initiated with the University of Connecticut.[2] Bacteria isolated from some 6,000 chips from decayed and discolored zones in 68 trees were included in the preliminary study. Isolations from non-discolored wood yielded only a few bacteria (mainly from beech) and fungi.

Many species of bacteria were isolated, but only a few species were isolated frequently from all trees. The principal bacteria were slime-producing, gram-negative, short rods with perichrichic flagellation. They were similar in morphology and physiology to members of the genus *Pseudomonas.* Other groups commonly isolated were identified tentatively as members of *Xanthomonas* and *Bacillus.*

Microscopic examinations revealed bacteria in vessels of dis-

[2] Taxonomic studies conducted by Dr. Benjamin Cosenza and Miss Mathilda McCreary, Department of Bacteriology, University of Connecticut.

colored wood in living trees, and they were often in intimate contact with fungi. Bacteria were isolated most frequently from moist tissues having a high pH.

Nematodes were obtained occasionally from advanced decay, and they suppressed the growth of mycelium in culture.

Successions of Organisms in Wounds

Bacteria and non-Hymenomycetes such as *Hypoxylon* spp., *Phialophora melinii,* and *Trichocladium canadense* were the first organisms to infect logging wounds. These were the organisms isolated most frequently from wounds less than 10 years old. Occasionally a decay fungus such as *Polyporus versicolor* infected wounds less than 10 years old. Usually, however, extensive decay columns were not associated with wounds less than 30 years old.

When decay fungi infected, they usually followed bacteria and non-Hymenomycetes and grew longitudinally through — but never beyond — the discolored tissues. While decay was occurring, the surrounding tissues continued to support bacteria and non-Hymenomycetes. Occasionally, when the decay process ceased radially, a hard rim developed around the hollowed column and

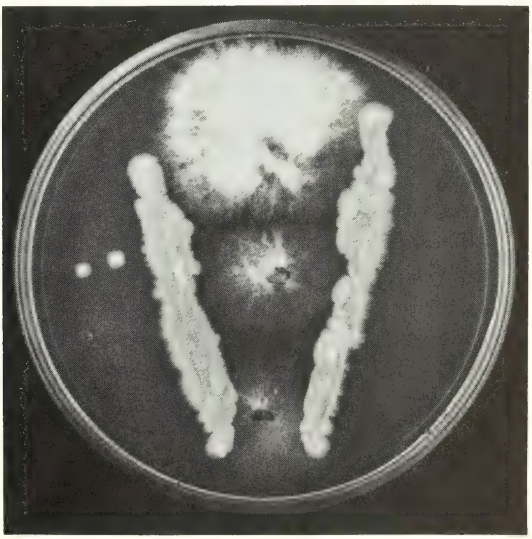

Figure 22.—Inhibition of *Fomes igniarius* by a bacterium isolated from the edge of a decay column that yielded the fungus.

the usual bacterium-fungus complex was absent. In these trees, the hard rim was contiguous with white uninfected wood (fig. 19).

Sometimes organisms were not obtained from the leading edges of discolorations advancing from recent wounds. Likewise, not all points along discolored columns yielded organisms. In such cases, however, organisms usually were obtained from areas behind the leading edges. In radial sections, organisms were obtained from bands of discolored wood adjacent to clear wood. Extensive isolation trials indicated that while organisms were present, they were not always distributed uniformly. Thus an organism isolated from one point might be absent from a point only an inch away.

Preliminary experiments indicated that while many non-Hymenomycetes grew well in culture with bacteria, most decay fungi were inhibited by them. A bacterium isolated commonly from edges of decay columns yielding *Fomes igniarius* not only inhibited growth of *F. igniarius* in culture, but the agar darkened where the two organisms grew near to each other. In culture, inhibition was related directly to the distance between the two organisms (fig. 22).

Preliminary Experiments on the Discoloration Process

Stem sections of vigorously growing young hardwoods were cut, debarked, and surface sterilized in 0.5-percent sodium hypochlorite (Clorox). Pieces approximately 1 inch in diameter and 4 inches long were placed upright in pint jars that had been autoclaved with 10 ml of water in them. Agar blocks supporting mycelium of the principal fungi isolated from discolorations were then placed on the pith of the stems in the jars. At least 25 stems were observed for each fungus. After 6 weeks, dark discolorations had developed in stems inoculated with *Phialophora* spp. and *T. canadense,* and tan discolorations developed in stems inoculated with *Hypoxylon* spp. No discolorations developed in stems autoclaved before inoculation or in the uninoculated controls.

Statistical Analyses of the Data on Yellow Birch, Sugar Maple and Beech

A total of 23 measurements and attributes by classes were recorded for all trees in this study (table 2). Only the data for yellow birch, sugar maple, and beech were subjected to analysis;[3] the other species had too few representatives to contribute an adequate sample. Since we wished to determine what factors affected the amount of decay and discoloration, the latter two (variables 18 and 19) were taken as the dependent variables. Pertinent tree, wound, and organism variables (1–11 inclusive) were included

[3] Analysis conducted by Dr. W. E. Waters, Assistant Director, Forest Insect and Disease Research, and Dr. R. W. Wilson and R. C. Peters, Biometrics Unit, Northeastern Forest Experiment Station, New Haven, Connecticut, Facilities of the Yale University Computer Center were used for the calculations.

Table 2.—*Data recorded on all trees*

Variable number	Description of variable
1	Age of tree when wounded.
2	Relative size of wound (percentage of circumference wounded).
3	Years since wounding.
4	Tree diameter at breast height.
5	Proximity to other entry point for decay and discoloration.
6	Type of wound (bark scrape; wood injury).
7	Index of wound size (greatest length x greatest width).
8	Occurrence of *Hypoxylon spp.* stromata.
9	Location of wound (feet from base).
10	Causes of wounds (skidding; felling).
11	Degree of healing (callus formation) 1 to 4.
12	Merchantable height of tree.
13	Gross cubic-foot volume.
14	Distance of decay above wound.
15	Distance of decay below wound.
16	Distance of discoloration above wound.
17	Distance of discoloration below wound.
18	Cubic-foot volume of decay.
19	Cubic-foot volume of discoloration (including decay when present).
20	Height of first branch stub above wound.
21	Circumference of tree.
22	Tree age.
23	Seams on tree.

as the independent variables. The remaining measured values or classified attributes were not pertinent or did not lend themselves to analysis in the form recorded.

The first analysis was a "full screen" of the associations between the respective dependent variables and the independent variables and of the intercorrelations among the latter. This technique involves the computation of all possible regressions of the dependent variable and the independent variables, taking the latter individually and in all combinations (Furnival 1965). For the present analysis, three variables judged most important in the relationships concerned were "fixed" in the full screen computations; i.e. they were included in all the regressions. These were: age of tree when wounded (variable 1), relative size of wound (variable 2), and years since wounding (variable 3).

The proportions of the total variation in amounts of decay and discoloration in the sample trees accounted for by the respective independent variables are shown in tables 3, 4, and 5. Several interesting points emerge. In yellow birch, there is a marked difference in the degree of association of variables 1–11 with decay (11.3 percent) and with discoloration (46.7 percent), while in sugar maple and beech there is no significant difference in this regard. In yellow birch, the three fixed variables accounted for most of the variation in both decay and discoloration. In sugar

Table 3.—*Significant statistical data for yellow birch*

Independent variables	Volume of decay, cubic feet	Volume of discoloration (including decay when present), cubic feet
	R^2	R^2
1 (Age of tree when wounded)	0.016	0.045
2 (Relative size of wound)	.006	.018
3 (Years since wounding)	.025	.400
1, 2, 3	.033	.416
All; 1 - 11	.113	.467

Regression equation: $Y = 0.031 + 0.284X$, Where Y = volume of discoloration and X = years since wounding.

Table 4.—*Significant statistical data for sugar maple*

Independent variables	Volume of decay, cubic feet	Volume of discoloration (including decay when present), cubic feet
	R^2	R^2
3 (Year since wounding)	0.261	0.281
3, 5 (5, Proximity to other entry points for decay and discoloration)	.344	.361
3, 5, 3 x 5	.462	.406
3, 5, 7, 3 x 5 (7, Index of wound size)	.563	.456
All; 1 - 11	.600	.550

Regression equations

$$Y_1 = -.653 + .0493\ X_1 + .0015\ X_2 + .0257\ X_3 - .0022\ X_4$$
$$Y_2 = -.927 + .0915\ X_1 + .0025\ X_2 + .0184\ X_3 - .0030\ X_4$$

Where Y_1 = Volume of decay, cubic feet; Y_2 = Volume of discoloration, cubic feet; X_1 = Years since wounding; X_2 = Proximity to other entry points for decay and discoloration; X_3 = Index of wound size (greatest length x greatest width); and X_4 = Interaction of years since wounding and proximity to other entry points for decay and discoloration.

Table 5.—*Significant statistical data for beech*

Independent variables	Volume of decay, cubic feet	Volume of discoloration (including decay when present), cubic feet
	R^2	R^2
7 (Index of wound size)	0.300	0.292
4 (Tree diameter at breast height)	.100	.108
3 (Years since wounding)	.085	.105
11 (Degree of healing)	.094	.098
3, 7	.345	.352
All; 1 x 11	.480	.540

Regression equations:

$$Y_1 = 0.0199 + 0.0070\ X_1$$
$$Y_2 = 0.4110 + 0.0128\ X_2$$
$$Y_1 = 0.6080 + 0.0066\ X_1 + 0.0268\ X_2$$
$$Y_2 = 0.9390 + 0.0119\ X_1 + 0.0576\ X_2$$

Where Y_1 = Volume of decay, cubic feet; Y_2 = Volume of discoloration, cubic feet; X_1 = Index of wound size; X_2 = Years since wounding.

maple, proximity to other entry points (variable 5), the interaction between years since wounding and other entry point proximity (variable 3 x variable 5), and index of wound size (variable 7) were significantly associated with the amounts of decay and discoloration, in addition to the mixed variables. In beech, index of wound size (variable 7), tree diameter at breast height (variable 4), and degree of healing (variable 11) appeared related to the dependent variables, in addition to the fixed variables.

Stepwise multiple regressions were then run for each tree species, using the indicated significant independent variables in turn. These analyses revealed that for yellow birch, years since wounding (variable 3) was the primary variable of importance. With sugar maple, years since wounding (variable 3) was the single most important variable; but proximity to other points of entry (variable 5), the interaction of these two variables, and index of wound size (variable 7) also were consistently associated with variation in the amounts of decay and discoloration. In beech, the age of the wound and index of wound size (variables 3 and 7) were shown to be most important. The pertinent regression equations are given in tables 3, 4, and 5.

Discussion and Conclusions

Decay and discoloration in living trees are the results of dynamic processes that involve interactions of organisms that in turn are affected by environmental factors, including the actions of man. When a dissected tree is examined, the decay and discoloration processes are observed as of that moment. And immediately thereafter other processes also begin to function.

The statistical analyses indicated that in yellow birch and to a lesser extent in beech the variables measured had more influence upon discoloration than upon decay. A similar situation was reported by Hepting *et al.* (1949), who stated that while discoloration about increment borer holes within a given species was very consistent, the occurrence of decay varied from tree to tree. In other increment-borer studies little or no discoloration or decay was associated with the injuries in balsam fir, spruce, pines, hemlock, hickory, oaks, white ash, and black cherry, while considerable discolorations and localized decay were found in beech, paper birch, yellow birch, and sugar maple (Campbell 1939). Northern hardwoods appear to differ greatly from other species in their susceptibility to decay and discoloration.

The events that begin when a tree is wounded and continue until the wood is destroyed all depend greatly on one factor: time. It takes time for changes in moisture and air to affect cellular processes, and for organisms to infect and invade tissues. Of all the independent variables tested, time was the most important. Similarly, time was important statistically in the development of decay of Appalachian oaks (Hepting 1941) and of softwoods in the Northwest (Wright and Isaac 1956).

The indication that size of wound was the most important independent variable tested for beech is very interesting. Insects (especially ants) that attacked the wounds, and the beech bark disease, may have been factors contributing to this. The unknown factors that appeared to have restricted the advancement of decay and discoloration in other species may have been disrupted in beech by the insect attacks. The callus around the wounds were attacked frequently by both species of scale insects and *Nectria* spp., and

such wounds were invaded frequently by *H. rubiginosum.* As wound size increased, greater numbers of these organisms infested and infected the callus tissue.

Also, we must account for the extremely small correlation (11 percent) between the independent variables and decay in yellow birch. Yellow birch had many white-faced wounds, which were associated with very little decay and discoloration; it had wounds infected by *P. obliqua,* a fungus that invaded tissues that formed after the tree was wounded; and it had wounds invaded by *P. squarrosa-adiposa,* an aggressive invader of tissues present when wounds were inflicted. Also, discoloration advanced rapidly in yellow birch; and when decay followed, the decay columns were not discrete and they were difficult to measure. These could have been some of the reasons for the low correlation.

On the other hand, decay and discoloration advanced slowly in sugar maple. These discrete columns could be measured easily.

The statistical analyses indicated that the data collected accounted for but little of the decay associated with wounds in yellow birch and therefore were not useful for prediction purposes. Approximately half of the variation in the amount of discoloration in the birch and of both decay and discoloration in sugar maple and beech was associated with the independent variables taken, and the regression equations derived will provide estimates of relatively low precision. Thus the statistical analyses show clearly that factors other than those recorded in this study must be considered. These analyses give greater emphasis to the importance of organisms and intrinsic factors in the decay-and-discoloration processes in living trees. The biochemical and physiological interactions of organisms and the tree tissues are undoubtedly part of the unknown revealed by the analyses. Decay and discoloration following logging wounds in northern hardwoods definitely cannot be explained or predicted on the basis of external characters or features alone.

Yet reliable predictive curves for decay following logging wounds have been plotted for other tree species (Wright and Isaac 1956) and for decays following fire wounds (Hepting 1935; Toole 1959; Hepting 1941).

The difference between the decay results obtained by Wright and Isaac (1956) and in this study may be attributed to differences in the trees studied, and to the fact that one fungus, *Fomes annosus* (Fr.) Cke., dominated the decays in the softwood study (63 percent of the rots on the Coastal Range). The uniformity brought about by the dominance of *F. annosus* rendered the data more suitable for analysis. By contrast there were so many organisms causing decays in northern hardwoods that no consistent relationship could be shown.

In studies of fire wounds on hardwoods in the South, Toole (1959) isolated 30 species of fungi but only 5 were responsible for 50 percent of the decay. Hepting (1935) also isolated many fungi but cited two, (*Lentinus tigrinus* Bull. ex Fr. and *Polyporus lucidus* Fr.) as most important in trees wounded by fire on the Mississippi Delta.

Another important difference between logging wounds and fire wounds lies in the nature of the wounds. No two logging wounds are alike; and even though they occur in one logging area, they may have been inflicted at different times. On the other hand, fire wounds all have somewhat similar patterns; and in a given area they often were inflicted at the same time. Fire wounds are at the base, and decay develops upward. The width of fire wounds 12 inches above ground were used consistently as the width of the wounds (Hepting 1941). These considerations are mentioned here only to indicate some of the differences between studies that at the outset appeared similar.

One of the most difficult problems encountered in this study was to measure columns of decay and discoloration that joined other columns advancing from other infection courts. Many measurements had to be discarded because it was impossible to distinguish the columns from different infection courts. The longitudinal dissections were necessary to get proper results. With cross sections alone it is hardly possible to assess the contributions to the major defect column of organisms from other infection courts. Also, cross-section measurements at intervals up a log are by themselves inaccurate because of the abrupt ending of defect columns in northern hardwoods. Defect within a log may be

missed entirely if the ends appear sound, or may be exaggerated when different defects, but similar in appearance, exist on the ends of the log.

The other principal infection court that complicated the measurement of logging-wound defects was the branch stub. Longitudinal dissections exposed many healed stubs, and revealed their influence on the internal defect column. Defects advancing from wounds often joined those already present that were associated with branch stubs. This explained to a great extent why some wounds had little defect associated with them, while similar wounds had extensive defect.

Cracks sometimes formed above and below logging wounds. Vasiloff and Basham (1963) pointed out that careful examination revealed that what seemed at first to be frost cracks often were cracks that formed above and below wounds. Nordin (1954) stated that frost cracks were the most important courts of entry for decay fungi in sugar maple in the area studied. My observations and those of Vasiloff and Basham (1963) suggest that mechanical wounds may initiate some of the cracks.

Trees with small cores of discoloration usually had little defect associated with logging wounds, compared to trees with large cores of discoloration. Because some mature trees had little or no discolored cores, the nature of this discoloration had to be determined. If these central discolored columns were "normal" and actually "heartwood" as they are called frequently (Bromley 1941), then the advancement of defects from logging wounds into this central discoloration would have to be treated as a normal phenomenon of wounded trees. Because the discolored cores were not uniform in size and shape in trees of the same size and age, and because the pattern of defects advancing from logging wounds into these columns was equally erratic, the columns were considered not to result from normal tissue changes. This was pointed out by Good *et al.* (1955) for sugar maple. Much confusion still exists over factors affecting true heartwood formation.

Jorgensen (1962) stated that, according to available information, heartwood is formed in live sapwood by changes in metabolism of dying cells exposed to aeration and/or desiccation. Chat-

taway (1952) discussed a transition zone that formed between heartwood and sapwood. In this study the dark central cores of the northern hardwoods studied were not considered to be true heartwood, but rather were considered to be wound-initiated discoloration (Shigo 1965b).

The nature of this central discoloration was investigated further because of its effect on the advancement of defects from logging wounds. Detailed accounts of this appear elsewhere (Shigo 1965a and 1965b). In northern hardwoods, the tissues formed subsequent to wounding (dead branches are considered wounds because they provide openings into trees) usually are not infected by organisms or affected by other processes that result in discolorations and decay. A similar statement was made by Nylinder (1955) for tissues formed after live branches were pruned from oaks. All trees lose some branches at different times, and wounds are formed. The extent of discoloration is affected by many factors, abiotic and biotic. As trees are wounded at different points over the years, discoloration columns form. These columns usually advance fastest near the pith, suggesting a reason for the central location of most columns. If a tree containing a large core of discoloration from prior wounds is again injured severely during logging, new infections advance into the central column. Larger wounds, or several wounds around the tree, sometimes initiate the processes that form new limits for columns of defect.

The advancement of decay and discoloration toward the pith suggests that aeration may be a factor affecting the process. Thacker and Good (1952) concluded that aeration was probably not important in decay of sugar maple, but, as pointed out by Zycha (1948) for European beech, aeration may be important in certain discoloring processes that do not involve organisms. Since organisms were not isolated consistently from discoloration around recent wounds in northern hardwoods, the first phase of the discoloration process may be the reactions occurring between wood tissues and air entering via the wounds. Many softrot fungi grow better than Basidiomycetes in wood with a high moisture content (Duncan 1960), and these fungi have a superior tolerance of poor aeration (Duncan 1961). Possibly excess aeration first stimulates

advancement of the discoloration, and then the organisms that follow bring about conditions of high moisture and low aeration. Bacteria and non-Hymenomycetes, but not Basidiomycetes, could thrive in such an environment and enhance the discoloration processes.

The specific factors accounting for the pattern of decay and discoloration in living trees are not known, but the frequency of isolation of bacteria suggests that bacteria are important in these processes. The deterioration of pine logs in storage by bacteria has been demonstrated (Knuth and McCoy 1962). Yet, except for studies of elm and poplar (Hartley *et al.* 1961), the role of bacteria in living forest trees has received little attention. The fact that most of the bacteria isolated in this study were motile suggests that they are not dependent entirely upon the translocation stream of the tree for their movement between cells.

The association of many species of non-Hymenomycetes with discolorations in northern hardwoods has been recognized (Nordin 1954; Lorenz 1944), but no detailed study has been made of these organisms. They often are isolated but not identified. Non-Hymenomycetes were often referred to as "contaminants" in investigations on other trees (Hepting 1935; Eslyn 1962). Eslyn (1962) stated that a number of "contaminants" were natural inhabitants of soft maple wood.

To my knowledge, *P. melinii* has not been reported previously from northern hardwoods. Species of *Phialophora* are common inhabitants of pulp and paper (Wang 1961; Melin and Nannfeldt 1934) and they have been isolated from timber showing soft rot (Savory 1954; Duncan 1960). The abundance of these fungi in living trees and their ability to persist in woodpulp makes them economically important.

Trichocladium canadense was called *Torula ligniperda* (Willk.) Sacc. (Hughes 1959)[4] by earlier investigators. The fungus has been recognized for a long time as a wood-inhabiting Hyphomycete (Siggers 1922) and as being associated with red-heart in birch (Fritz 1931; Campbell and Davidson 1941). Its intimate

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[4] Personal communication from R. W. Davidson, Colorado State University.

association with bacteria was pointed out by Campbell and Davidson (1941).

Phialophora spp. and *T. canadense* are similar in several respects. They are dark, are associated with bacteria, are isolated from moist tissues having a high pH, and produce phialophores. Such conidiophores are well adapted to spore production in confined areas. Phialophores producing spores of *Phialophora* sp. were observed in cells of discolored tissues in living trees. How long these spores remain viable, and whether or not they move through some of the tissues, are questions that need answers. Possibly spores produced in abundance are stimulated to germinate and develop by changes in tissues induced by wounding.

Chlamydospores of *Torula ligniperda* (*Trichocladium canadense*) also have been observed in wood (Siggers 1922; Fritz 1931). Such spores may be able to live under conditions not suitable for mycelium.

Hypoxylon spp. were the principal pioneer fungi that infect wounds. The primary species isolated from wounds on northern hardwoods was *H. rubiginosum.* Miller (1961) stated that in the herbaria of the world, forms of *H. rubiginosum* have been given almost every other *Hypoxylon* name possible. Yet, many *Hypoxylon* species are probably either missed, not identified, or mistaken for a Hymenomycete because of their erratic fruiting habits in culture. In an otherwise excellent account of the species of *Hypoxylon,* Miller (1961) makes little or no mention of the imperfect stages encountered in culture. A study of the cultural characteristics of the species is needed. Fungi in the Xylariaceae are often cited as examples of non-Hymenomycetes that decay wood (Merrill *et al.* 1964). Apparently these fungi compete successfully with all other invading fungi. They were cited as some of the first fungi to invade fire wounds (Hepting 1941). On northern hardwoods, fruiting bodies of *Hypoxylon* spp. and the Basidiomycete *Stereum complicatum* commonly occurred on the same wound. Toole (1959) stated that *S. complicatum* was also a pioneer on fire wounds.

Hypoxylon spp. were the principal fungi isolated from wood of oak trees that had been girdled as part of the control for oak wilt

in West Virginia (Shigo 1958). These fungi seem to be aggressive wound-invading organisms.

The importance of *Pholiota squarrosa-adiposa* as an aggressive decay fungus that invades logging wounds was pointed out. With this fungus the value of isolating rather than relying upon observation in the forest is demonstrated, for it produces a sporophore that persists for but a short time. For this reason, assessment of fruiting in the forest would not adequately reveal its importance.

The close association of bacteria, non-Hymenomycetes, and Hymenomycetes in living trees suggests that all are important in the processes that result in decay and discoloration (Shigo 1964). The results of this study emphasize the need for greater understanding of the many factors that affect processes resulting in decay and discoloration in living trees.

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An annotated BIBLIOGRAPHY of WATERSHED MANAGEMENT RESEARCH by the Northeastern Forest Experiment Station, 1931-65

by Howard W. Lull

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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
RALPH W. MARQUIS, DIRECTOR

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This Bibliography . . .

THIS bibliography contains annotated citations to 156 publications in forest-watershed-management research produced by the staffs of the Allegheny and Northeastern Forest Experiment Stations from January 1931 to April 1965. Twenty-one of these publications antedate the formal establishment of watershed-management research at the Northeastern Station on July 1, 1948.

The publications listed here are arranged alphabetically and chronologically by author. An asterisk (*) preceding the item indicates that copies of reprints of the publication are available from the Northeastern Forest Experiment Station, 6816 Market Street, Upper Darby, Pa. An author index will be found at the end of the bibliography.

Annotation and assembly of a bibliography of this kind provides an excellent opportunity to view and assess research results. Certain groupings become manifest: some papers obviously present new knowledge; a number review and embroider it for different audiences; a number simply state that problems for research exist and due to their importance, a research program is needed, or planned, or under way; others, written for colleagues, describe how research is done, often giving detailed descriptions of instrumentation and analytical methods; and an occasional publication will carry the burden of reviewing and correlating research results from different geographical or technical fields.

In evaluating research results of the past quarter century, some trends and generalizations become apparent. Following are some of the highlights of research accomplishments in watershed management.

Humus

The role of humus in forest hydrology was clarified: It appears that under present forest conditions the water-storage capacity of humus is 1 to 3 inches less than the potential capacity that can develop under full protection; further, the degree to which the forest floor remains intact after cutting indicates

the extent to which the beneficial hydrologic effects of the forest may still be present.

Infiltration and Overland Flow

From observation and measurement, infiltration is not limited and overland flow is not produced in forest areas where humus and litter are intact, even when these areas have been heavily cut over, except from very unusual heavy rainfall of prolonged high intensity. Overland flow is produced from logging roads and landings when the forest floor has been scraped or worn away, and the soil compacted.

Concrete Frost

Concrete frost has been observed in all types and conditions of forest stands but never of a magnitude to produce overland flow of any consequence.

Snow Accumulation and Melt

Snow accumulates to greater depths—and melts and disappears earlier in the spring—in the open and under hardwoods than under conifers. Accumulation remaining thereafter under conifers may produce peak flows during unusual warm spells. A mixed cover of hardwoods, conifers, and open land should lengthen the melting season and ameliorate peak flows.

Forest Cutting and Water Yield

Increases in water yield from forest cutting on shallow, stony soils in West Virginia are inversely related to the forest cover left on the area. Commercial clearcutting produced the greatest annual increase, about 5 area-inches of water. Most of the increase appeared during the growing season. Cost of the increased water yield, in terms of treatment cost and loss in timber income, amounted to $0.04 per 1,000 gallons. Yield increases were smaller each year after cutting; they were negligible after 6 years on the commercial clearcutting, sooner than that in the partial cuttings.

Forest Cutting and Peak Flows

Substantial increases in storm flow, which sometimes occur after clearcutting, are due to reduction in transpiration and soil drying rather than to drastic changes in amounts of overland, subsurface, or groundwater flows.

Sedimentation

Sources of sedimentation in forest areas are limited to the disturbed area described above and to channel-cutting. Erosion from logging roads may be minimized by proper road location and drainage, and sediment may to a large extent be kept out of streamflow by locating roads at stipulated distances from channels. Erosion from logging roads constructed on stony soils may be strongly and rapidly reduced by formation of a rock pavement.

Herbicide Pollution

In studies where forest vegetation was killed by basal, stump, and foliage sprays of 2,4,5-T, no significant herbicide contamination appeared in streamflow.

Regional Streamflow

For watersheds of 100-square miles or less in area, there was a significant difference in annual, seasonal, and storm flows between and within physiographic regions. Within regions there was considerable similarity between streamflow of experimental watersheds and the average regional streamflow.

Research Methods

In instrumentation and analytical methods, experience was drawn upon to prepare monographs on construction of stream-gaging-stations for research on small watersheds, and on the all-important procedure of calibrating watersheds before treatment. Correlation and review papers covered the subjects, among others, of soil compaction, forest humus, and light. In research problems, perhaps the most significant were the importance of municipal watersheds in the Northeast and the need to find means of broadening both the fundamental basis and the practical application of research results.

But That is Not All

This compilation and review is strictly limited to the watershed research conducted by the Northeastern Forest Experiment Station. It may enable a reader to find out what has been done here and what publications have been prepared and are available. But this is a small drop in a big bucket. Forest watershed research is conducted by other agencies in the Northeast, at universities, and in other regions. And there are many disciplines not functionally tied to forest watershed research whose research results impinge upon it. Obviously there must be a continual cross-fertilization of ideas and methods, and at times a summing-up such as this.

The Publications

(1) Behre, C. Edward. 1932. **Are further studies needed on the relation of forests to water supply in New England?** Jour. New England Water Works Assoc. 46: 170-175.

In the Northeast, water-resource problems chiefly concern suppliers for municipal use and for power. Southern New England is already using about one-sixth of its potential water supply. If streamflow can be made more uniform and flood peaks reduced through control of vegetation, a larger proportion of water yield could be utilized with a given reservoir storage capacity. Research is needed to determine the effect of vegetative cover of various kinds on quantity, regularity, and quality of streamflow.

(2) Behre, C. Edward. 1932. **The relation of forests to the water supplies of New England.** Water Works Engin. 85: 276-279.

A briefer version of the same material described above.

(3) Belotelkin, K. T. 1940. **Soil freezing and forest cover.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Tech. Note 37. 4 pp.

In northern New Hampshire before snowfall the soils in the open froze before forest soil. Open soil froze solid whereas forest soil, when frozen, maintained good permeability far into the winter. Frost penetration was least in the hardwoods, deeper in the open, and deepest in the spruce swamp where, because of interception, snow depth was shallowest. Frost remained in the ground longer under softwoods than in the open or under hardwoods. Frost disappeared earliest under the hardwoods.

*(4) Bethlahmy, Nedavia. 1951. **An alinement chart for use with the fiberglas soil-moisture instrument.** Soil Sci. 71: 377-380, illus.

An alinement chart is described that shortcuts computations involved in computing soil moisture from resistance readings obtained with the fiberglas soil-moisture instrument. Results are well within the limits of accuracy of charts provided with the instrument.

(5) Bethlahmy, Nedavia. 1951. **Distant earthquakes affect local ground-water levels.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Res. Note 9: 1-3.

Ground-water levels at the Delaware-Lehigh Experimental Forest in eastern Pennsylvania fluctuated a few hundredths of a foot with occurrence of severe earthquakes in India and British Columbia. Checking ground-water-level records against notices of earthquakes throughout the world, the author found that levels were being affected by distant earthquakes every 8 to 12 days.

(6) Bethlahmy, Nedavia. 1952. **A method for approximating the water content of soils.** Amer. Geophys. Union Trans. 33: 699-706, illus.

A procedure is described for calibrating fiberglas soil-moisture units and for preparing tables needed to convert resistance readings into inches of water. Shapes and slopes of calibration curves were determined in the

laboratory and their positions along the moisture-percent scale were determined by field calibration. Estimates of bulk density based on soil depths and moisture content were used to convert moisture percentages into inches of water.

*(7) Bethlahmy, Nedavia. 1952. **Why do plants wilt in cold weather?** Ecology 33: 301-303, illus.

Studies of soil freezing indicate that, when a soil is frozen, the fiberglas soil-moisture units react as though the soil had been desiccated. A frozen soil is, physiologically, a dry soil. Concrete frozen soil is equivalent to a soil that is below its wilting point in moisture content. Thus a plant growing in frozen soil has no moisture available for growth; if it transpires, it will wilt. Frost, root, and snow depths are influencing factors. These relationships can determine the advisability of fall planting of conifers.

*(8) Bethlahmy, Nedavia. 1953. Discussion of **Frost penetration into soils as influenced by depth of snow, vegetative cover, and air temperatures,** by Clyde E. Bay, George W. Wunnecke, and Orville E. Hays. Amer. Geophys. Union Trans. 34: 635-637.

Gypsum blocks and fiberglas units can be used to measure movement of frost into and out of the soil, but resistance measurements do not indicate frost type. Also, frozen soil may draw moisture from lower unfrozen horizons, thus changing the type of frost without a change in resistance readings.

(9) Bethlahmy, Nedavia. 1953. **Estimating summer evapotranspiration losses in a Pennsylvania scrub oak forest.** Soil Sci. Soc. Amer. Proc. 17: 295-297, illus.

Soil moisture was measured with fiberglas units, and losses were calculated daily for periods when soil was below field capacity. A significant relationship between losses and saturation deficit was found; the regression coefficient was related to the percentage of sand in the soil profile. Calculated evapotranspiration losses checked well against the water balance of the experimental watersheds.

(10) Bevan, Arthur. 1947. **Flood control surveys in the Northeast.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 10. 9 pp., illus.

The Omnibus Flood Control Act of 1936 directed the Secretary of Agriculture "to make preliminary examinations and surveys for runoff, and waterflow retardation, and soil erosion prevention." The Forest Service has been engaged in surveys on the Allegheny, Connecticut, and Merrimac watersheds. Purpose of the surveys is to develop a comprehensive program for flood control based primarily on land-use management effects on runoffs. Costs and benefits of the proposed programs are estimated. The approach to flood control is a comprehensive integrated program including engineering structures and land-use structures that will produce the most flood control for the least cost.

(11) Bjorkbom, John C., and George R. Trimble, Jr. 1958. **Sow seed on logging roads to control erosion.** Northeast. Logger 7: 18-19, 36-37, 46, illus.

Several combinations of seed, lime, and fertilizer successfully revegetated

and stabilized bare soil of logging roads in the White Mountains of New Hampshire. Two seeding mixtures are suggested for heavily shaded roads and three for open or lightly shaded roads. Lime and fertilizer are necessary. Seeding is particularly needed on steep pitches and on grades over 5 percent cut deeply into mineral soil, and on raw and unstable cut and fill banks.

(12) Day, Gordon M. 1940. **Topsoil changes in coniferous plantations.** Jour. Forestry 38: 646-648.

Soils of 18 conifer plantations in Vermont and New York were compared with those in adjacent openings. In 18 to 61 years the plantations accumulated 6,000 to 38,000 pounds of forest floor material per acre. Plantations with mull humus showed an increase in organic content of the upper layers of mineral soil. Where mors developed, the topsoil had less organic matter than open areas under grass cover. Surface layers of mineral soil in the plantations were about twice as permeable to water as those in open areas. Differences in percolation between the planted and open areas were much greater in the mull types than in the other types.

(13) Diebold, C. H. 1940. **Strip planting for flood control.** Jour. Forestry 38: 810-812.

Crown closure and humus development were studied in 17 fully stocked coniferous plantations in southwestern Pennsylvania in order to assess flood-control benefits. Crowns of Scotch and pitch pines planted 4 x 4 or 5 x 5 feet closed in 6 to 8 years; planted 6 x 6 or 7 x 7, 1 to 3 years longer. Pitch and Scotch pine closed 2 to 4 years earlier than red and white pine. Norway spruce closed in 12 to 15 years where planted 4 x 4 or 5 x 5. Pitch pine planted 5 x 5 developed a humus layer of 1½ to 2 inches in 15 years; other pines developed somewhat shallower layers. Little or no humus was found under Norway spruce. Strips of pine, hardwood, and shrubs for game food, 10 to 20 rows wide, are suggested for flood control.

(14) Dunford, E. G., and Sidney Weitzman. 1955. **Managing forests to control soil erosion.** *In* **Water.** U. S. Dept. Agr. Yearbook 1955: 235-242.

Outlines principles of integrating timber and watershed management to control erosion from forest lands. Describes factors responsible for accelerated erosion from forest lands. Recommends measures of fire prevention, grazing control, logging, and construction of logging roads for erosion control.

*(15) Eschner, Arthur R. 1960. **Effect of scrub oak and associated ground cover on soil moisture.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 133. 16 pp., illus.

Soil was consistently wettest on areas where scrub-oak overstory and ericaceous groundcover had been deadened, and driest on undisturbed areas. An area covered chiefly by sheep laurel generally had the second lowest soil-moisture content, and a bare area from which the natural humus layer and several inches of topsoil had been removed was generally intermediate in rank. A site treatment that completely deadens low-growing vegetation will make maximum amounts of water available to

planted seedlings. Deadening the scrub oak alone will not reduce transpiration losses by any appreciable amount.

(16) Eschner, A. R., B. O. Jones, and R. C. Moyle. 1957. **Physical properties of 134 soils in six Northeastern states.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 89. 23 pp., illus.

Mechanical analysis, organic-matter content, plasticity, bulk density, and soil-moisture contents at saturation and field capacity are given for 134 soils in the six Northeastern States from Pennsylvania to New Hampshire. Regressions express the relationship of bulk density to organic-matter content and soil texture.

*(17) Eschner, Arthur R., and Jack Larmoyeux. 1963. **Logging and trout: four experimental forest practices and their effect on water quality.** Progressive Fish-Culturist 25: 59-67, illus.

Clearcutting a West Virginia watershed resulted in significantly higher maximum stream temperatures, above those generally tolerated by brook trout. The increase in dissolved solids noted was not great enough to affect stocking. Late summer and early fall increases in streamflow from the cutting would be beneficial to trout, for they come at a time when flow in many trout streams is dangerously low. High turbidities would be detrimental to trout.

*(18) Eschner, A. R., and D. R. Satterlund. 1963. **Snow deposition and melt under different vegetative covers in central New York.** U. S. Forest Serv. Res. Note NE-13, p 66., illus. Northeast. Forest Expt. Sta., Upper Darby, Pa.

Analysis of snow measurements in 5 cover types in the Allegheny Plateau suggests that if a warm period comes early in the spring, forest snow melt contributes less and slower runoff than open areas. But when warm weather comes late, and with an appreciable snowpack only in the forest, the reverse should be true. A mixture of forest cover and open area may provide the best land-use control of snowmelt runoff.

*(19) Felton, Paul M., and Howard W. Lull. 1963. **Suburban hydrology can improve watershed conditions.** Public Works 94: 93-94, illus.

Infiltration measurements in woods, fields, and lawns in Philadelphia's suburban Wissahickon watershed showed that relative infiltration under present land-use is about one-half of what it was for forested conditions, and it has dropped 10 percent by reason of land-use changes since 1950. Methods by which suburbanites may increase infiltration are discussed.

(20) Flaccus, Edward. 1958. **Landslides and their revegetation in the White Mountains of New Hampshire.** Ph.D. dissertation, Department of Botany, Duke Univ., Durham, N. C.

About 550 slides in the White Mountains were studied to determine the factors contributing to their occurrence and the nature of their revegetation. The immediate cause of slides is the sudden failure of internal resistance to downslope movement—resulting from a complex of interacting factors. Heavy rainfall was found to be the single most important contributing factor when slope steepness ranged from 25-35 degrees. Slides

are not likely to occur on slopes that do not exceed 25 degrees. They occur naturally and are not appreciably affected by man's activity. The degree of revegetation is related to slide features—bare cliffs and ledges, talus or rock debris, gullies, residual areas, and deposit areas.

*(21) Fletcher, Peter W., and Howard W. Lull. 1963. **Soil-moisture depletion by a hardwood forest during drought years.** Soil Sci. Soc. Amer. Proc. 27: 94-98, illus.

In Butler County, Missouri, during two drought years, daily soil-moisture measurements were taken in a mixed oak-hickory stand in plots that were bare, had litter only, trees only, and trees and litter (no treatment). As compared with undisturbed soil at field capacity, litter removal increased soil drying rates about 10%; tree removal decreased them about two-thirds; removal of both trees and litter decreased soil drying rates about one-third. Soil-moisture regimens are interpreted with respect to tree mortality due to drought. Upland sites with subsoil pan formations are especially vulnerable to periodic drought losses.

(22) Forbes, R. D. 1931. **Watershed cover and water conservation.** (Address delivered before the annual meeting of the Maryland and Delaware Water and Sewerage Assoc., Wilmington, Del.) U. S. Forest Serv. Allegheny Forest Expt. Sta. 7 pp.

Results from recent studies on use of water by forest vegetation, percent runoff from areas under different land use, and influence of forest cover on surface runoff and evaporation suggest possibilities of increasing water supplies by vegetation management. Revenue from recreational use of watersheds may help in acquisition of watershed lands by water companies. Research on forest influences will be undertaken by the U. S. Forest Service. The Allegheny Station has asked for funds for studies in the headwaters of the Allegheny River and on the watershed of some large city on the Atlantic Seaboard. A plant physiologist, soils expert, silviculturist, and meteorologist should be employed on each study.

(23) Forbes, Reginald D. 1934. **Ruling the river.** Sci. Monthly 38: 524-533.

The influence of forests on streamflow has been argued in connection with acquisition and administration of the national forests and in connection with the Mississippi River flood of 1927. Complexities of forest influences are brought out in a review of the climactic and geological factors that affect streamflow, and the role played by the forest, particularly the influences of forest humus on water-holding capacity of the soil and on percolation, and the influences of the canopy on interception and snow-melt. Whether the forest influences are beneficial or detrimental depends upon region and season. For instance, Appalachian forests are indispensable to well-regulated streamflow. In southern California, however, canyon-bottom forest uses excessive amounts of water. More knowledge of forest influences is needed.

(24) Forbes, R. D. 1936. **Forests and flood control.** Pa. Forest Leaves 26: 19-20.

Foresters have accomplished little in determining the influence of forest cover on streamflow. No research of this kind has been conducted in the

Northeast. Urges that streamflow and weather records for 125 streams in the Allegheny area that have been gaged for more than 5 years should be assembled, together with forest data, and studied to give at least preliminary information on the relationship of forests and streamflow.

(25) Fridley, Burley D. 1953. **Home-made gadgets aid forest-influence research.** Jour. Forestry 51: 907-908, illus.

Three home-made devices have proved helpful: (1) an ordinary bucket made into a simple stove for thawing ice and snow in rain gages; (2) a spring clamp for holding a measuring tape to a stake when measuring erosion on road cross-sections and (3) a portable datum level for measuring erosion on logging roads where reference stakes cannot be used on the road.

(26) Garland, Lloyd E., Robert S. Pierce, and George R. Trimble, Jr. 1959. **A soil survey of forest land.** Jour. Soil and Water Conserv. 14: 199-204, illus.

A modification of detailed soil-surveying methods on farmlands is described for use in mapping extensive areas of woodland in the Northeast, as worked out at the Hubbard Brook Experimental Forest in New Hampshire. Mappable topographic, soil, and geologic factors are considered that would broadly define the growing potential and watershed-management aspects of any area of woodland. Certain criteria are set up to indicate logging and road-building limitations.

(27) Gedney, Donald R. 1949. **Land abuse, a flood, and then more floods.** Pa. Forest Leaves 34: 17.

Destructive use of forest land in northwestern Pennsylvania set the stage for the damaging flood of July 17-18, 1942, which cost 15 lives and millions of dollars worth of damage. Floods in this area were infrequent before this; but since that flood, the worst on record. annual and semi-annual floods have occurred. A remedial program of better land-use management is needed.

(28) Grossman, Sidney J. 1941. **Comments on strip planting for flood control.** Jour. Forestry 39: 728-730.

In opposition to Diebold's paper (1940) the author questions the flood-control benefits brought about from crown closure, points out instances where frost remained 7 to 10 days longer in conifer plantations than in the open, where infiltration rates were lower in plantations than in the open, and raises economic questions that should be considered in choices of species and spacing of conifer plantations.

(29) Hale, Charles E., and G. R. Trimble, Jr. 1950. **Permanent wilting percentages of glacial soils in the Northeast.** Jour. Soil and Water Conserv. 5: 135-136.

Moisture contents of soils at permanent wilting were determined during a drought the summer of 1949 in the upper Susquehanna river watershed in New York state. Percent moisture contents by weight and volume are given for humus layers and soil horizons.

*(30) Hart, George. 1961. **Humus depths under cut and uncut northern hardwood forests.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Forest Res. Note 113. 4 pp.

In a stand of high site quality on the Bartlett Experimental Forest in New Hampshire, H-layers in 1959 averaged 2.35 inches deep in an area clearcut in 1939, 2.95 inches deep in an area thinned in 1937 with 40 percent of the volume removed, and 3.37 inches deep in an uncut stand. Differences were not so great in a stand of lower site quality: comparable depths were 2.05, 2.27, and 2.33 inches.

*(31) Hart, George. 1963. **Snow and frost conditions in New Hampshire, under hardwoods and pines and in the open.** Jour. Forestry 61: 287-289, illus.

At maximum snow accumulation there was no significant difference in snow-water contents between the open field (6.8 inches) and a 40-to-50-year-old hardwood stand (7.0 inches). Forty-year-old white pine and red pine plantations had maximum contents of about 5.0 inches. Differences were attributed mainly to canopy density. Order of snow disappearance was: (1) open field, (2) hardwoods, (3) red pine, (4) white pine. Melt rates were 0.10, 0.05, and 0.04 inches per day for hardwoods, white pine, and red pine respectively. Yearly differences in temperature and snow depth produced large variations in occurrence of concrete frost.

*(32) Hart, George, and Howard W. Lull. 1963. **Some relationships among air, snow, and soil temperatures and soil frost.** U. S. Forest Serv. Res. Note NE-3, 4 pp., illus. Northeast. Forest Expt. Sta., Upper Darby, Pa.

Winter temperatures of air, snow, and soil measured on snow-covered and bare plots near Laconia, N. H., showed an increase in temperature and reduction in its temporal variation going from air to snow to soil. Twelve inches of snow will prevent soil freezing at air temperatures down to 5° F, and 6 inches of snow down to 25° F.

*(33) Hart, George, Raymond E. Leonard, and Robert S. Pierce. 1962. **Leaf fall, humus depth, and soil frost in a northern hardwood forest.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Forest Res. Note 131. 3 pp.

Annual leaf accumulation under a second-growth northern hardwood forest in New Hampshire in the mound-and-depression microtopography typical of the region averaged 1,478 pounds per acre on mounds, 2,582 on slopes, and 5,515 in depressions. Humus depths averaged 2.0, 3.5, and 7.1 inches for the three sites respectively. Greater depths of leaves and humus in the depressions protected the soil from concrete frost.

*(34) Hornbeck, James W. 1964. **The importance of dew in watershed-management research.** U. S. Forest Serv. Res. Note NE-24, 5 pp. Northeast. Forest Expt. Sta., Upper Darby, Pa.

From May through November 1962 monthly dew deposition at the Fernow Experimental Forest in West Virginia ranged from 0.017 to 0.055 inch. Dew or frost was recorded on 111 of the 200 days of record. Total deposition during July, August, and September was 0.131 inch, or 1.2 percent of the precipitation. For any one month the error in precipitation measurements probably exceeds dewfall. Dewfall is probably not large enough to warrant measurement in watershed-management studies.

*(35) Hornbeck, J. W., and K. G. Reinhart. 1964. **Water quality and soil erosion as affected by logging in steep terrain.** Jour. Soil and Water Conserv. 19: 23-27, illus.

A study at the Fernow Experimental Forest in West Virginia has shown that excessive damage to water quality can be avoided even when logging on steep terrain. Measured maximum stream turbidities were 56,000 ppm. on a commercial clearcut area where skidroads were steep and close to the stream and only 25 ppm. on an intensive selection-cut watershed where skidroad location was carefully planned to prevent eroded materials from reaching the stream channel. Most of the damage to water quality occurred during and immediately after logging. Recommended practices include planning of the logging operation; proper location, drainage, and grade of skidroads; and timely completion of the operation.

*(36) Hornbeck, James W. 1965. **Accuracy in streamflow measurements on the Fernow Experimental Forest.** U. S. Forest Serv. Res. Note NE-29, 8 pp. Northeast. Forest Expt. Sta., Upper Darby, Pa.

Sources of error were evaluated in respect to stream-gaging instrumentation, stage-discharge relation, hook-gage measurements, and compilation of data. Total error from all sources was estimated to be about 3 percent of annual streamflow values.

(37) Hough, A. F. 1945. **Frost pocket and other microclimates in forests of the northern Allegheny Plateau.** Ecology 26: 235-250.

Frost pockets result from heavy cutting followed by forest fires. Once opened, these areas persist for many years. Conversion to good forest depends on fire protection, reduction of browsing by deer and rabbits, and possibly planting of frost-resistant conifers. Partial cuttings should be the rule in all forests on the high plateau, especially on topography susceptible to formation of frost pockets.

*(38) Lavigne, Raymond W. 1960. **A time-corrector device for adjusting streamflow records.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Forest Res. Note 98. 4 pp., illus.

A plexiglas graph was constructed with time corrections on the vertical scale and days of record on the horizontal, to prorate time corrections on streamflow charts. Adjustable arms were attached for determining 8- and 15-day corrections, the most common periods used. This device eliminates the necessity of making a separate graph for each time-scale correction. It can be adapted for making time corrections for precipitation and hygrothermograph charts.

*(39) Leonard, Raymond E. 1961. **Interception of precipitation by northern hardwoods.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 159. 16 pp., illus.

A study of rainfall interception at the Hubbard Brook Experimental Forest during two growing seasons showed that net precipitation (throughfall plus stemflow) averaged 87 percent of precipitation measured in the open. During the leaf period it averaged 82 percent, and in the leafless period 88 percent. Rainfall that ran down the tree stems amounted to 5 percent of that measured in the open. Stemflow from a 10-inch

beech for a 1-inch storm amounted to 30 gallons of water or to a depth of about 7 inches of water at the base of the tree.

(40) Leonard, Raymond E. 1961. **Net precipitation in a northern hardwood forest.** Jour. Geophys. Res. 66: 2417-2421, illus.

Throughfall and stemflow measurements for two growing seasons were related to gross storm rainfalls by linear regressions. Net precipitation averaged 87 percent of gross rainfall, of which 82 percent was rainfall and 5 percent was stemflow. Large differences in amounts of stemflow were found among various hardwood species. American beech had twice the stemflow of yellow birch.

*(41) Leonard, Raymond E., and Kenneth G. Reinhart. 1963. **Some observations on precipitation measurement on forested experimental watersheds.** U. S. Forest Serv. Res. Note NE-6, 4 pp. Northeast. Forest Expt. Sta., Upper Darby, Pa.

Exposure of precipitation gages as a result of clearcutting a West Virginia watershed reduced annual catch by a little less than 3 percent and winter catch from 3 to 7 percent. Tilting precipitation gages did not give the increased catch that had been reported in the West, probably because the gages were protected somewhat from the wind. Vertical gages provide an index of precipitation on the watershed. Tilted gages, when exposed on representative slopes and aspects, will give absolute estimates.

*(42) Little, Silas, Howard W. Lull, and Irwin Remson, 1959. **Changes in woodland vegetation and soils after spraying large amounts of waste water.** Forest Sci. 5: 18-27, illus.

Waste water from a food-processing plant in New Jersey, sprayed onto woodland at a rate of 400-600 inches a year, has killed off practically all trees and native shrubs and herbs and stimulated a rank growth of elder and common field weeds. Soils have remained highly permeable; forest floors have deepened and become more mull-like. Continuing high rates of water absorption are ascribed to the undisturbed soil condition and the protective forest floor that breaks the impact of spray.

(43) Lull, Howard W. 1955. **Water supplies and our forest.** Pa. Forests 45: 58-60.

Defines and describes forest watershed management and considers present and future demands for water, the importance of forested watersheds to water-supply problems, and the watershed research program of the Northeastern Station.

(44) Lull, Howard W. 1957. **Forest watershed management research in Pennsylvania.** Pa. Forests 37: 41-42, illus.

Forest watershed-management research was begun in Pennsylvania in 1948 at the Delaware-Lehigh Experimental Forest to find methods of converting scrub oak to commercial timber and to determine the effect of this conversion on streamflow. Daily streamflow and climactic records have been published in a series of three progress reports, each covering 2 years of record. Prediction equations for monthly, seasonal, and annual streamflow have been developed. Watershed research was started at the Pocono Experimental Forest in 1949. Snow and frost studies were made in the Pocono Plateau in 1950-52, and recently periodic snow surveys were

started in the Allegheny Plateau. Other areas where watershed research is needed include the Ridge and Valley Region.

(45) Lull, Howard W. 1957. **What they said about forests and floods in Pennsylvania 50 to 75 years ago.** Pa. Forests 37: 91-92, 107.

Early conservationists in Pennsylvania were deeply concerned about the effect of forest cutting on the water resources, as evidenced by a succession of statements and reports in the Annual Reports of the Commonwealth's Board (later Department) of Agriculture and Department of Forestry from 1877 to 1901-02. Interest in this subject abruptly lessened with acquisition of state forest lands in 1897.

(46) Lull, Howard W. 1958. **Better water through forest management.** *In* **Better water through forestry and engineering:** 10-19. Interstate Comn. on Potomac River Basin. Washington, D. C.

Outlines forest watershed problems in the Potomac River basin, various measures undertaken to improve the situation, and research under way to determine what effects forest type and condition have on water yield, distribution, and quality.

*(47) Lull, Howard W. 1958. **Municipal watersheds in the Northeast.** Jour. Amer. Water Works Assoc. 50: 979-982.

There are more than 300 forested watersheds in the Northeast from which municipalities draw part or all of their water supplies. Numbers and areas of watersheds are listed, by states, and largest areas are noted. Management plans have been prepared for several watersheds. Possibilities of increasing water yield by forest cutting are considered, and watershed research in the Northeast is described.

*(48) Lull, Howard W. 1959. **Soil compaction on forest and range lands.** U. S. Dept. Agr. Misc. Pub. 768. 33 pp., illus.

A review of the literature on soil compaction on forest and range lands as related to soil and water conservation: the compaction process; the extent of compaction by logging, grazing, and other agencies; the effects of compaction by logging and trampling on soils, soil-water relations, and vegetal growth; and remedies for compaction and methods of preventing or minimizing it.

*(49) Lull, Howard W. 1959. **Humus depth in the Northeast.** Jour. Forestry 57: 905-909, illus.

Humus depth under virgin spruce-fir in mountains of the Northeast ranged from 8 to 16 inches, under hemlock and hardwoods in the Adirondacks from 3 to 9 inches, and from 2 to 5 inches elsewhere in the Northeast. Except for spruce in the White Mountains and hemlock in the Adirondacks, the depths under virgin stands are about 1 inch greater than present accumulations under sawtimber-poletimber stands. Pertinence of humus depths to flood protection is considered.

*(50) Lull, Howard W. 1960. **Watershed management research in the Northeast.** Jour. Forestry 58: 285-287.

Forest watershed research programs are conducted in 7 of the 12 Northeastern States by the U. S. Forest Service, U. S. Geological Survey, the

Cities of Baltimore, Md., and Newark, N. J., Yale University, Syracuse University, and the Pennsylvania State University. In all, 30 experimental watersheds are being studied to determine how forest cover and changes in cover affect streamflow.

*(51) Lull, Howard W. 1960. **Forested municipal watersheds in the Northeast.** Jour. Forestry 58: 83-86.

Forested municipal watersheds and forest-bounded reservoirs provide and protect water supplies for 360 municipalities in the Northeast, total well over 1 million acres of forest land, and serve about one-third of the region's population. Originally set aside for protection of water supplies, many of these areas are now managed also for forest products. Examples are given.

*(52) Lull, Howard W. 1962. **Management for water production on municipal watersheds.** World Forestry Cong. Proc. 5: 1686-1690.

Few if any of the forested municipal watersheds in the United States are now being managed to regulate water yield, yet increasing demands for water indicate need for such management. Possible approaches are suggested. Logging methods, erosion control, and pros and cons of recreation on watersheds are discussed.

*(53) Lull, Howard W. 1963. **Forest influences research by questionnaire.** Jour. Forestry 61: 778-782.

Early conservationists employed polls to find out the effects of forest cutting on streamflow. For instance, around the 1900's the states of New York, Pennsylvania, and Ohio queried engineers and long-time residents as to their opinions. More recently, the director of forestry in South Africa conducted a similar poll. Most of those polled believed that forest cutting had reduced streamflow, though there were some differences of belief.

(54) Lull, Howard W. 1964. **Ecological and silvicultural aspects.** *In* **Handbook of applied hydrology:** 6-1 to 6-30, illus. McGraw-Hill Book Co., New York.

The proportion of precipitation intercepted by forest vegetation, the rate of infiltration of water into the soil, and the amount of water evapotranspired tend to increase as ecological succession proceeds from the preclimax to the climax condition, or with silvicultural practices that increase the density of vegetation. Exceptions are noted.

(55) Lull, Howard W. 1964. **Some recent results from forest watershed research.** Soc. Amer. Foresters Allegheny Sect. Proc. 1964: 44-48.

Recent research results suggest some new concepts in forest-streamflow relationships and some practical management applications. Among items considered were reduction in sedimentation rates from logging roads, overland flow and flood peaks from a heavily cutover watershed, snowmelt contributions to flood peaks from conifers and hardwoods, small watershed research application to large watersheds, sources of base flow, and the use of silvicides on watersheds.

(56) Lull, Howard W., and John H. Axley. 1958. **Forest soil-moisture relations in the Coastal Plain sands of Southern New Jersey.** Forest Sci. 4: 2-19, illus.

Soil-moisture measurement during the growing season on upland sites in the New Jersey Barrens indicated that stands of shortleaf pine and scrub oak used about the same amount of water at about the same rate from the upper 5 feet of soil. Both removed moisture to a depth of at least 12 feet. Seven-year-old pine and oak-sprout stands removed moisture as rapidly and at the same depth as older oak stands. A 15-year-old shortleaf pine stand utilized moisture to a depth of 8 feet, and a bare area dried to a depth of 6 feet.

(57) Lull, Howard W., and Peter W. Fletcher. 1962. **Comparative influence of hardwood trees, litter, and bare area on soil-moisture regimen.** Univ. Mo. Agr. Expt. Sta. Res. Bul. 800, 15 pp., illus.

In a mixed oak-hickory stand in Butler County, Mo., pairs of plots were treated to obtain the following conditions: trees and litter (no treatment), trees only, litter only, and bare. Daily soil-moisture readings were taken to determine the soil-moisture regimen. During two growing seasons the litter-only plots were wettest, and the trees-only plots dried most rapidly. Summer rainfalls were stored, for the most part, in the top 20 inches of soil. Rates of moisture loss tended to decrease with increasing depth. Watershed management implications are examined.

(58) Lull, Howard W., and Ralph W. Marquis. 1957. **Forests guard the Potomac.** *In* **Upstream Conservation.** Interstate Comn. on Potomac River Basin: 44-58, illus. Washington, D. C.

Forest influences on Potomac streamflow are discussed in relation to forest-use of water; the effects of forest cutting, planting and composition on water yield; and effects on flood peaks and water quality. A program of forest watershed protection is recommended.

(59) Lull, Howard W., and Robert S. Pierce. 1959. **Frost and forest soil.** Internatl. Union Geodesy and Geophys. Pub. 48 vol. 1: 40-48.

Average depths of concrete frost in 14 forest-condition classes in the Northeast and the percentage of days concrete frost occurred during the frost period are compared with frost depth and occurrence in four open-land use conditions. Average depth ranged from 4.7 to 6.2 inches in open lands, 2.5 to 3.5 inches in conifer stands and hardwood reproduction, and 1.2 to 2.5 inches in hardwood stands. Percentage occurrences in the above order were 57 to 80, 17 to 44, and 12 to 20. Forest watershed management implications are considered.

*(60) Lull, Howard W., and Robert S. Pierce. 1960. **Prospects in the Northeast for affecting the quantity and timing of water yield through snowpack management.** Western Snow Conf. Proc. 1960: 54-62.

Snowfall, snowmelt runoff, and the influence of forest cover on snow accumulation and melt are evaluated in respect to flood prevention and

water yield. Areas of management possibility lie largely in New York and northern New England, where one-third to one-half of the average annual streamflow comes from snowmelt and rainfall in April and May.

*(61) Lull, Howard W., and Irvin C. Reigner. 1957. **A program of watershed-management research on forest lands in the Upper Delaware and Susquehanna River basins.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 92. 33 pp., illus.

Water, forest, and soil resources are described and watershed research problems of 7 regions are noted. A 5-point program is proposed, designed to provide the information needed for the management of forested watersheds in the area.

*(62) Lull, Howard W., and Francis M. Rushmore. 1960. **Snow accumulation and melt under certain forest conditions in the Adirondacks.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 138. 16 pp., illus.

In the spring of 1959, maximum snow accumulation in hardwood sapling and sawtimber stands contained 2 more inches of water than the snowpack in balsam fir and red spruce stands. Snow melted about twice as fast in hardwood stands as in conifer stands and disappeared about 9 days earlier. In mixed conifer and hardwood stands, accumulation and melt were intermediate. Accumulation and melt were correlated with canopy closure, as measured with a spherical densiometer.

*(63) Lull, Howard W., and Francis M. Rushmore. 1961. **Further observations of snow and frost in the Adirondacks.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Forest Res. Note 116. 4 pp., illus.

Snow-depth and water-content measurements in March and April 1960 were checked against values predicted with procedures developed in 1959. Predicted and actual values were very close. During 51 days of snow interception observation, average snow depth on balsam fir branches was 2.13 inches, on red spruce 1.84, white pine 1.78, and hemlock 1.18. Concentrations of concrete frost were found beneath conifer crowns where snow was shallowest.

(64) Lull, Howard W., and Francis M. Rushmore. 1962. **Influence of forest cover on snow and frost in the Adirondacks.** Eastern Snow Conf. Proc. 1961-62: 71-79, illus.

Maximum accumulation of snow-water in mid-March 1959 in a northern hardwood stand was 9.01 inches as compared to 6.92 inches in a red spruce-balsam fir stand; by mid-April the greater melt rate in the hardwoods had more than erased this 2-inch difference. Maximum accumulation and rates of melt were related to canopy closure as measured with a spherical densiometer, and predictions were checked against 1960 data. Snow catch on branches of various conifers was related to their form and needle habit. Concrete frost tended to form beneath conifer crowns in the snow-interception zone.

*(65) Lull, Howard W., and Donald R. Satterlund. 1964. **What's new in municipal watershed management.** Soc. Amer. Foresters Proc. 1963: 171-175.

Recent research shows that forested watersheds can produce high-quality

water when carefully logged. A review of the effects of clearcutting on water yield shows that first-year water yields are increased about 4 to 8 inches. Reforestation over a 20-year period has reduced annual yield about 5 inches. In two studies, cost of increasing water yield was 4 cents and 21 cents per 1,000 gallons of increased yield. A method of evaluating low flow occurrence and persistence is given.

*(66) Lull, Howard W., and Herbert C. Storey. 1957. **Factors influencing streamflow from two watersheds in northeastern Pennsylvania.** Jour. Forestry 55: 198-200, illus.

Comparison of the Lehigh and Lackawaxen watersheds (located about 12 miles apart) offers an example of the difference that forest cover, land use, and soil make in the streamflow of two watersheds that have similar climate. Annual maximum daily flows of the Lackawaxen were consistently greater than Lehigh values, and annual minimum daily flows lower. The Lehigh was 93 percent forested, the Lackawaxen 61 percent. Most soils of the Lackawaxen were poorly drained while the Lehigh soils were better drained.

*(67) Lull, Howard W., and Norman R. Tripp. 1958. **The management of forested watersheds in New England.** Jour. New England Water Works Assoc. 72: 341-349.

Describes how quantity and quality of water from a forested watershed is influenced by type of forest cover, cutting treatments, and logging operations, with some practical management suggestions based on water shed research.

(68) Lull, Howard W., and others. 1962. **Forest land management in watershed programs.** Chapter III (23 pp.). *In* **Watershed management.** FAO Occas. Paper 13. Rome.

The protective function and water-yield effects of forest management on streamflow are discussed in respect to reforestation, logging, fire, disease, and insect attack. Watershed-management techniques for protection and for increasing water yield are described in terms of general principles, and examples are given of applications to several environmental situations: intense cold, snow, high and low rainfall, deep or shallow soils, and slow or rapid growth.

*(69) McLintock, Thomas F. 1959. **Soil moisture patterns in a northern coniferous forest.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 128. 5 pp., illus.

A brief description of major soil-moisture trends in relation to the hummock-and-hollow topography of a mixed pine-fir-spruce stand near Orono, Maine. Moisture content of soils in hummocks dropped below saturation 1 to 2 weeks before that in hollows. Differences suggest that hummock positions may have more favorable growing conditions early in the season when the soil is wet, and may be but little more adverse when the soil is dry.

(70) McQuilkin, W. E., E. F. McNamara, Irvin C. Reigner, and Howard W. Lull. 1955. Report No. 3: **Forest and Water Research Project, Delaware-Lehigh Experimental Forest.** Pa. Dept. Forests and Waters. 44 pp., illus. Harrisburg.

Progress in cooperative watershed and scrub-oak-conversion studies is

described with some notes on fire control. Tabular daily data from watershed study include precipitation, air temperature and other climatic factors, streamflow, groundwater levels, soil moisture content, and soil freezing, for October 1952 to September 1954.

(71) Mitchell, Wilfred C., and G. R. Trimble, Jr. 1959. **How much land is needed for the logging transport system?** Jour. Forestry 57: 10-12, illus.

At the Fernow Experimental Forest 4.8 to 7.0 percent of the area was used for skidroads in road systems located by loggers' choice and from 2.5 to 4.6 percent in systems located by foresters. Careful planning by foresters can reduced skidroad areas by 40 percent. Average grade of loggers' roads ranged from 14 to 21 percent and of foresters' roads, 9 to 15 percent.

(72) Morey, H. F. 1931. **Climatological charts for the Allegheny forest region.** Mo. Weather Rev. 59: 18-28.

Average annual and summer temperatures, mean maximum and minimum summer temperatures, average dates of first frost in fall and last killing frost in spring, average annual precipitation, average summer precipitation, and average length of growing season are indicated on maps of Pennsylvania, Maryland, New Jersey, and Delaware. Climate of the beech-birch-maple type is worked out from these maps, and the climatic significance of the dividing line that marks the southern limit of oak and the northern limit of loblolly pine is discussed.

(73) Morey, Harold F. 1942. **The application of our knowledge of the organic layers of the soil profile to flood control.** Pa. State Coll. School Engin. Tech. Bul. 27: 143-151.

Changes in humus depth following clearcutting and regrowth of grazed and ungrazed conifers and hardwoods were studied during the Connecticut Flood-Control Survey. After clearcutting, humus reduction is greater and the rate of accumulation slower in temporary than in long-lived hardwoods. Light partial cutting had little effect on humus depth. In 70-year-old stands of long-lived hardwoods on medium soils, humus depth in ungrazed woodland is more than twice that in grazed woodland.

(74) Munns, E. N., W. R. Chapline, R. D. Forbes, L. F. Kellogg, and H. G. Meginnis. 1933. **Watershed and related forest influences.** *In* **A national plan for American forestry.** 73d Cong. 1st Sess. Sen. Doc. 12: 299-461.

Magnitude of national problems of streamflow and erosion are described in relation to domestic and industrial water supplies, irrigation, water power, navigation, floods, and erosion. The role of forest management in solving these problems is considered in relation to how forest cover influences runoff and erosion, and consequences of forest fires, logging, grazing, and other agencies on runoff and erosion. The influence of the forest on watershed problems, and the present condition and effectiveness of the forest in exerting this influence are given for 17 drainage regions. Forest areas in each region are classified according to their influence on streamflow regulation, erosion control, and other watershed values into three groups: major influence, moderate influence, and slight to no influence.

(75) Northeastern Forest Experiment Station. 1948. **Delaware-Lehigh Experimental Forest, the first unit of the Delaware Basin Research Center.** U. S. Forest Serv. Northeast. Forest Expt. Sta. 6 pp., illus. Upper Darby, Pa.

A brief description of the objectives of scrub-oak conversion and watershed studies.

*(76) Northeastern Forest Experiment Station. 1962. Proceedings: **Watershed management research conference on collection and compilation of streamflow records.** U. S. Forest Serv. Northeast. Forest Expt. Sta., 65 pp.

A conference was held at Laconia, N. H. to review methods of collecting and compiling streamflow data, to learn about recently developed machine methods for handling data, and to compare costs. Papers, discussion, and summaries are given.

*(77) Northeastern Forest Experiment Station. 1964. **Hubbard Brook Experimental Forest.** U. S. Forest Serv. Northeast. Forest Expt. Sta. 13 pp., illus.

A brochure describing watershed research at Hubbard Brook and the major water problems of the mountainous forested region of New England —low floods, floods, and water quality. The research program involves an inventory and assessment of the components of the hydrologic cycle, determination of the effect of forest cutting on streamflow, and the translation of single-treatment effects on small watersheds into multiple-treatment effects on large ones. Vegetation, geology, soils, climate, and research facilities of the Experimental Forest are described.

(78) Pierce, Robert S. 1965. **Forest watershed management in the Northeast.** Univ. Maine, Maine Forester 1965: 48-52.

Floods, low streamflow during summer months, and sedimentation are the principal forest water-resource problems. Research by the Northeastern Forest Experiment Station on these problems is described, with particular attention to the program at the Hubbard Brook Experimental Forest in New Hampshire.

*(79) Pierce, Robert S., Howard W. Lull, and Herbert C. Storey. 1958 **Influence of land use and forest condition on soil freezing and snow depth.** Forest Sci. 4: 246-263, illus.

A two-winter study of frost and snow in 18 different land-use conditions (bare cultivated fields to mature forest) was conducted at 6 locations in the Northeast. Concrete frost depth in hardwood stands was about one-half that in conifer stands. Concrete frost was observed over twice as often in open as in forest lands, and occurred twice as often in conifers as in hardwoods. Based on accumulated depth, three categories of frost intensity were classified: high for open-land conditions, intermediate for brushy land and conifer stands, and low for hardwood cover. Snow accumulated to greater depth in the forest than in the open, and in hardwoods than in conifers.

(80) Reigner, Irvin C. 1951. **Erosion studies on the Schoharie Watershed, New York.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 44. 17 pp., illus. Upper Darby, Pa.

Sedimentation of Schoharie reservoir was measured in 1950, when drought had dropped water levels to record lows. Accumulated sediment had reduced total capacity by 1.75 percent in 24 years. Fifty-five percent of the watershed is covered with forest and 43.5 percent is in grass. Forty-six percent of the watershed was moderately eroded; 80 percent of this area was in grass. Only 0.39 percent of the watershed was severely eroded. Road banks, streambanks, and reservoir shore lines contributed about 6 percent of the sediment. Better grazing practices would do much to prevent erosion. A thorough study of the watershed, with view to planning a land-use program, is recommended.

*(81) Reigner, Irvin C. 1963. **A vinyl-lined weir for small watershed studies.** Jour. Forestry 61: 297-298, illus.

An inexpensive weir to gage small streams was built of wood and lined with a sheet of vinyl film. The cost was about $850 (including labor and instrumentation) and the weir is expected to last 5 to 10 years without repair. Construction details are given.

*(82) Reigner, Irvin C. 1964. **Calibrating a watershed by using climatic data.** U. S. Forest Serv. Res. Paper NE-15, 45 pp., illus. Northeast. Forest Expt. Sta., Upper Darby, Pa.

In a single-watershed calibration of the 1,529-acre forested experimental Dilldown Watershed in Pennsylvania, equations were developed for predicting annual runoff and monthly water loss or runoff. The basic relationships were developed from streamflow, climatic, groundwater, and soil-moisture records; but final equations were expressed in terms of runoff and climatic variables only. Standard errors of estimate were well below the minimum change in yield considered significant; namely, 10 percent of the annual or monthly runoff.

*(83) Reigner, Irvin C. 1964. **Evaluation of the trough-type rain gage.** U. S. Forest Serv. Res. Note NE-20, 4 pp. Northeastern Forest Expt. Sta., Upper Darby, Pa.

Trough gages used to measure throughfall under vegetation and rainfall in the open at the Dilldown Watershed in Pennsylvania gave deficient catches due to rainfall splashing out of the trough. The deficiency was inversely related to the slope of the trough, and correction regressions were computed. A 90° and 120° V-shaped trough may give a better catch than the semicircular trough used in this study, for raindrops would not bounce vertically from the sloping sides.

*(84) Reigner, Irvin C. 1964. **How to make a wind-movement recorder from any spare drum-type recorder.** U. S. Forest Serv. Res. Note NE-21, 4 pp., illus. Northeast. Forest Expt. Sta., Upper Darby, Pa.

A recording instrument that has a clock-driven chart drum and pen-arm assembly may be converted to a wind-movement recorder with a $5 expenditure for an electromagnet, dry cells, and assorted small hardware. Dry cells are connected in series with the anemometer contacts and the

electromagnet. Closure of contacts activate the magnet, a counterweight, and the pen-arm. If no instrument is available the necessary parts may be purchased for about $80.

(85) Reigner, Irvin C., William R. Byrnes, and E. F. McNamara. 1958. **Forest watershed management research in the Ridge and Valley Section of Pennsylvania.** U. S. Forest Serv. Northeast. Forest Expt. Sta. 7 pp., illus.

The Leading Ridge Experimental Watershed is a cooperative watershed research project of the Pennsylvania Department of Forests and Waters, The Pennsylvania State University, and the Northeastern Forest Experiment Station of the U. S. Forest Service. Streamflow of three watersheds is being gaged and climatic measurements are taken. Forest, soil, and geological surveys are planned and 25 possible studies are listed.

*(86) Reigner, I. C., W. E. McQuilkin, and E. F. McNamara. 1961. Report No. 4: **Forest and water research project, Delaware-Lehigh Experimental Forest.** Pa. Dept. Forests and Waters. 97 pp., illus. Harrisburg.

This is the fourth progress report on results of the scrub oak conversion studies and calibration of the Dilldown watershed. A single-watershed calibration was developed, based on prediction of annual and monthly runoff from climatic variables. Daily streamflow and climatic data are tabulated for 4 water-years, October 1954 to September 1958.

*(87) Reigner, I. C., and John J. Phillips. 1964. **Variations in bulk density and moisture content within two New Jersey Coastal Plain soils, Lakeland and Lakehurst sands.** Soil Sci. Soc. Amer. Proc. 28: 287-289.

A relationship between bulk density and soil depth plus stone content was developed for Lakeland sand and Lakehurst sand in the Coastal Plain of New Jersey. From this, bulk density was estimated for each soil-moisture sample from five 1-foot layers, and moisture contents by weight were converted to moisture content by volume. Variations in bulk density and moisture content within and between the relatively closed-space plots are given for each of the 1-foot layers.

*(88) Reigner, I. C., W. E. Sopper, and R. R. Johnson. 1964. **Control of riparian vegetation with phenoxy herbicides and the effect on streamflow quality.** Northeast. Weed Control Conf. Proc. 18: 563-570.

To determine the extent of streamflow contamination by herbicides, vegetation along the stream channels of two small forested watersheds was sprayed with 2,4,5-T by means of a mistblower. Water samples were taken just above and below the treatment area and 1 mile downstream immediately after spraying, 4 hours later, and for several days thereafter. Contamination was found in samples taken within 4 hours of treatment just below the treated area and later after a 1-inch rain. There was no contamination 1 mile downstream. If mist-sprayed with normal precautions, phenoxy herbicides can be used on municipal watersheds.

*(89) Reigner, I. C., and Walter C. Sushko. 1960. **The Baltimore watershed . . . an example of good management.** Public Works 91: 85-88, illus.

The development of municipal watershed management by the City of Baltimore is described, from the building of its first water-supply reservoir in 1862 to its present system of three water-supply reservoirs surrounded by 17,300 acres of forested watershed land. The Watershed Control Division manages the forest land for water protection, timber products, and recreation. Conifers have been planted on 2,299 acres. Three small watersheds are being gaged and studied to determine the effect of forest treatment on water yield.

(90) Reinhart, K. G. 1958. **Calibration of five small forested watersheds.** Amer. Geophys. Union Trans. 38: 933-936, illus.

Problems and methods are described for calibrating five watersheds on the Fernow Experimental Forest in West Virginia in order to determine effects of different cutting methods on streamflow. Five years of record gave high correlations in streamflow characteristics between watersheds. Length of the calibration was determined and treatment assignments made.

*(91) Reinhart, K. G. 1960. **A simple filter dam for small streams.** U. S. Forest Serv. Northeast. Forest Expt. Sta. Forest Res. Note 107. 4 pp., illus.

Four simple log-and-post dams were built to filter sediment out of muddy streamflow coming from a heavily cut forested watershed with poorly located skidroads. In the year after logging, the dams trapped about 350 cubic feet of sediment, an amount equivalent to an average of 70 parts of soil per million parts of water.

(92) Reinhart, K. G. 1961. **The problem of stones in soil-moisture measurement.** Soil Sci. Soc. Amer. Proc. 25: 268-270.

Soil-moisture measurements by gravimetric sampling can be improved by removing stones from the samples and deducting their weight from the total soil weight and the weight of moisture in the stones from the weight of moisture in the sample. Correcting for stone content helps remove the moisture-content variation due to the variation of the proportion of stones in different samples. To obtain moisture volume, bulk density of stone-free material must be calculated. To apply stone-free volumetric moisture contents on an areal basis requires estimation of the volume of the profile occupied by stones. In effect the disproportionate amount of stones in the original sample is removed and a proportionate amount substituted.

(93) Reinhart, K. G. 1963. **Efficient logging protects water quality.** South. Lumberman 206 (2567): 39, 42.

Research results from the Fernow watersheds in West Virginia showed that with proper planning and construction of skidroad systems, serious damage to water quality could be avoided. Maximum turbidities occurred during the logging operation. On the clearcut watershed average turbidity during logging was 490 ppm.; the first year after, 38 ppm.; and the next year, 1 ppm. Careful planning reduced length of skidroad system by 35 percent.

*(94) Reinhart, K. G. 1964. **Approximating soil-moisture storage in experimental watersheds by means of precipitation and streamflow records.** Soil Sci. Soc. Amer. Proc. 28: 575-578, illus.

Reliable estimates of total soil-moisture storage capacity of an experimental watershed may be difficult to obtain, particularly in a forested watershed, because of variations in and difficulties of measuring soil depth, root depth, soil texture, bulk density, stone content, and moisture content. Precipitation minus runoff—in selected periods when ample precipitation follows a dry spell—can provide an estimate of soil-moisture storage capacity. The method is illustrated with data from the Fernow Experimental Forest in West Virginia and is applied to two other watersheds in the Northeast. Limitations of the method are pointed out.

*(95) Reinhart, K. G. 1964. **Effect of a commercial clearcutting in West Virginia on overland flow and storm runoff.** Jour. Forestry 62: 167-171, illus.

A commercial clearcutting was made on a 74-acre gaged watershed; skidroads were constructed without grade limitations or provisions for drainage. After-logging infiltration rates in the watershed remained well above maximum rainfall intensities except on portions of the skidroads. Overland flow occurred only from the skidroads; it resulted from the combination of rain directly on the skidroads and interception of subsurface flow by the road cuts. Increased storm runoff in the growing seasons—up to a maximum of about ½ area-inch in any one storm—was largely the result of decreases in field-moisture deficiency rather than changes in the proportions of surface and subsurface flow. In judging hydrologic condition of logged areas, perhaps as much emphasis should be placed on road condition and forest-floor disturbance as upon the amount of timber cut and the condition of the stand.

(96) Reinhart, K. G. 1964. **Forest watershed research by the U. S. Forest Service in West Virginia.** W. Va. Water Res. Symposium Proc. 1963: 55-56.

Research begun in 1948 at the Fernow Experimental Forest, Parsons, West Virginia, has shown that erosion from logging operations can be controlled by practical and economical methods, that most of the harmful effects of logging are the results of disturbance of the forest floor, and that forest management does influence water yield. Future research will involve study of the energy budget and potential evapotranspiration, snowmelt, and forest microclimate.

*(97) Reinhart, K. G. 1964. **Frequency of streamflow measurements required to determine forest treatment effects.** U. S. Forest Serv. Res. Note NE-23, 7 pp., illus. Northeast. Forest Expt. Sta., Upper Darby, Pa.

Streamflow data from control and clearcut watersheds at the Fernow Experimental Forest were reanalyzed to determine if measurements taken once a day, twice a week, once a week, twice a month, or once a month could be used instead of continuous records to determine the effects of forest treatment. The results suggest that, under some situations, much might be learned from relatively few measurements.

(98) Reinhart, K. G. 1965. **Herbicidal treatment of watersheds to increase water yield.** Northeastern Weed Control Conf. Proc. 19: 546-551.

Before clearcutting a portion of an experimental watershed on the Fernow Experimental Forest during the winter of 1963, all trees above 1-inch d.b.h. were basal sprayed with 2,4,5-T in No. 2 diesel oil. After cutting sawlogs and pulpwood, all stumps were sprayed with the same mixture. In the following May and June the foliage of residual vegetation was sprayed with 2,4,5-T with knapsack mistblower. During these treatments numerous water samples were obtained from the stream immediately below the treatment area and sniff-tested. There was no evidence of contamination by the herbicide. The watershed treatment increased water yield from the treated area by almost 200,000 gallons per acre during May-October 1964.

(99) Reinhart, K. G., and A. R. Eschner. 1962. **Effect on streamflow of four different forest practices in the Allegheny Mountains.** Jour. Geophys. Res. 67: 2433-2445, illus.

After a 6-year calibration period, four forested watersheds were cut with practices ranging from a commercial clearcutting to a light selection cutting. Annual streamflow increased up to 5 area-inches on the clearcut watershed the year after treatment. Most of the increase came in the growing season. From May to October 1959, increases were 3.0, 1.8, 1.4, and 0.3 area-inches for per-acre cuts of 8.5, 4.2, 3.7, and 1.7 thousand board feet, respectively. Effect on water quality was related directly to degree of care taken in logging and skidroad planning. Effects of treatments are diminishing with passage of time.

*(100) Reinhart, K. G., A. R. Eschner, and G. R. Trimble, Jr. 1963. **Effect on streamflow of four forest practices in the mountains of West Virginia.** U. S. Forest Serv. Res. Paper NE-1, 79 pp. illus. Northeast. Forest Expt. Sta., Upper Darby, Pa.

Four intensities of forest management, ranging from commercial clearcutting to an intensive selection cutting, were applied on calibrated watersheds. Increases in annual flow ranged from 5.1 to 0.3 area-inches in relation to volume cut. Most of the flow increase came during the growing season. Road location and drainage affected water quality. Maximum turbidities ranged from 56,000 ppm. on the watershed with unplanned and undrained skidroads to 25 ppm. on the watershed with carefully planned skidroads. Effects of treatment are diminishing with time.

*(101) Reinhart, K. G., R. E. Leonard, and G. E. Hart. 1961. **Automatic devices to take water samples and to raise trash screens at weirs.** Northeast. Forest Expt. Sta. Forest Res. Note 112. 7 pp., illus.

The sediment sampler and trash-screen lifter are activated by tripping devices that operate when the water level in the weir basins reaches a predetermined height. When the sediment sampler is tripped, a hose connected to a sampling bottle drops into a flume carrying a portion of the streamflow. When the bottle is filled, its weight lifts the hose from the flume. The trash screen is removed when the head of water through the weir-notch is between 0.2 and 0.3 feet.

(102) Reinhart, K. G., and John J. Phillips. 1959. **Poor logging makes muddy streams.** W. Va. Conserv. 22: 20-23, illus.

Clearcutting a watershed in the Fernow Experimental Forest where skidroads were located without consideration of water value produced water turbidities up to 50,000 ppm. Before logging, turbidities had been less than 10 ppm. Much stream damage can be avoided by carefully planning a skidroad system. The better logging methods not only reduce erosion but are also cheaper for the operator.

*(103) Reinhart, K. G., and Robert S. Pierce. 1964. **Stream-gaging stations for research on small watersheds.** U. S. Dept. Agr. Handb. 268. 37 pp., illus.

Construction of stream-gaging stations is described, from selection of site and station design to detailed procedures for construction of a sharp-crested 120° V-notch weir. Necessary instrumentation for measurements of water level, and station operation and maintenance — including cold weather maintenance — are described. Gives costs of construction and a partial list of gaging stations used for small-watershed research in the United States. Numerous photographs and drawings illustrate various construction features, examples of instruments, and types of gaging stations.

(104) Reinhart, Kenneth G., and George R. Trimble, Jr. 1962. **Forest cutting and increased water yield.** Jour. Amer. Water Works Assoc. 54: 1464-1472, illus.

Cutting four watersheds at the Fernow Experimental Forest in West Virginia gave increases in annual streamflow, depending on the amount of timber removed, ranging from 8,000 to 140,000 gallons per acre. With regrowth of vegetation 4 years after cutting, increases had almost disappeared. During logging of the clearcut watershed, streamflow turbidity averaged 490 ppm., the next year it dropped to 38 ppm., and the next year to 1 ppm. Sedimentation was associated much more closely with the method of logging than with the amount of timber cut.

*(105) Sartz, Richard S. 1955. **Skidroad erosion.** Northeast. Logger 4(1): 10-11, 51, illus.

Modern logging methods with machines such as the bulldozer, which exposes mineral soil, have brought an erosion problem to the White Mountains of New Hampshire. Undisturbed forest soils are quite safe from erosion. But once the litter and humus are scraped away the soil can be washed away at startling rates. The solution is to prevent erosion by careful location and drainage of logging roads.

*(106) Sartz, Richard S. 1957. **Influence of land use on time of soil freezing and thawing in the Northeast.** Jour. Forestry 55: 716-718, illus.

During the winters of 1950-51 and 1951-52, open-land soils froze before softwood forest soils, and softwood forest soils froze before hardwood forest soils at six study areas from south-central Maine to northeastern Pennsylvania. Open-land soils thawed before softwood forest soils, but after hardwood forest soils. Dates of frost disappearance depended in part on frost depth. The number of days from first frost on open land to first frost on forest land ranged from 3 to 47 on softwood plots and 26 to

48 on hardwood. Number of days from last frost on open land to last frost in the forest ranged from 0 to 26 for softwoods, and from −22 to 4 for hardwoods.

*(107) Sartz, Richard S. 1957. **Snow and frost measurements in a watershed-management research program.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 96. 6 pp., illus.

Periodic measurements of frost and snow on a small gaged watershed in the Hubbard Brook Experimental Forest in New Hampshire are described and first winter (1955-56) results given. Little concrete frost was found in hardwood stands. Differences between snow-water measurements by gage (with Alter shield), snowboard, and snowpack for a 6-week period were not significant.

(108) Sartz, Richard S., and William D. Huttinger. 1950. **Some factors affecting humus development in the Northeast.** Jour. Forestry 48: 341-344, illus.

Studies during flood-control surveys of the Allegheny River watershed showed that humus depth increased with age of stand until maximum foliage production was reached. At any given age, humus depths tended to be greater under well-stock stands. Stand density controls the balance between organic accumulation and decomposition. The destructive effects of logging, fires, and grazing on humus depend on their intensity and frequency or duration. Northeast slopes seem to develop deeper humus, and microtopographic features cause extreme variations in humus depth. Heavy texture soils apparently develop deeper humus than sandy soils.

*(109) Sartz, Richard S., and George R. Trimble, Jr. 1956. **Snow storage and melt in a northern hardwoods forest.** Jour. Forestry 54: 499-502, illus.

A study of snow storage and melting behavior in the White Mountains of New Hampshire indicates that snow accumulation in hardwood forests could be increased and the snowpack prolonged by cutting narrow openings in an east-west direction. Openings in a pole stand had 7 to 10 percent more snow water than the woods, and openings in a sawtimber stand had 4 percent more. Slowest melting was in the south sector of openings.

(110) Satterlund, Donald R., and Arthur R. Eschner. 1963. **Forest watershed management in New York.** 32 pp., illus. N. Y. State Univ. Coll. Forestry, Syracuse.

Forest-watershed management problems of six water-resource regions are noted and their relative importance is assessed. Research is needed to determine the limits within which forest watershed management can be expected to be effective in increasing water yield, the flood-control potential of the forest area in the Allegheny Plateau, New England Upland, and the Catskills, and the integrated net effect of changes in land use on streamflow. In view of increasing water needs, the potential damage from floods, and the fact that one-half of the State's land is forested, a program of forest-watershed research should be undertaken in New York State.

(111) Satterlund, Donald R., and Arthur R. Eschner. 1964. **Snowmelt studies on the Tully Forest in central New York.** Eastern Snow Conf. Proc. 1964: 14-22, illus.

Accumulated figures of snowmelt for open, hardwood, and conifer areas

on the Tully Forest for the winter 1961-62 were applied to the cover types of the Albright Creek (largely open) and Shackham Brook (largely forested) watersheds and related to their actual runoff. After March 28 little snow remained on Albright and peak rates were generated from snow remaining on Shackham. Results suggest again that a desirable pattern of land use on the Allegheny Plateau, for improved streamflow regimen, would be a combination of open and forested lands.

*(112) Satterlund, Donald R., and Arthur R. Eschner. 1965. **The surface geometry of a closed conifer forest in relation to losses of intercepted snow.** U. S. Forest Serv. Res. Paper NE-34, 16 pp., illus. Northeast. Forest Expt. Sta., Upper Darby, Pa.

On the basis of equations for turbulent heat and vapor transfer, and reasoned application of knowledge about intercepted snow, the authors predicate great differences in the energy and vapor balance between an intercepted "snowfield" and one on level open ground. The differences, resulting from the complex surface geometry of a closed conifer forest, are sufficient to account for considerably greater losses from intercepted snow.

(113) Shirley, Hardy L. 1935. **Light as an ecological factor and its measurement.** Bot. Rev. 1: 355-381.

A review of literature about the effects of light on plants, light relationship of submerged plants, light in the forest, light intensity and quality requirements of vegetation, light and succession, and light measurement.

*(114) Sopper, William E., and Howard W. Lull. 1965. **Streamflow characteristics of physiographic units in the Northeast.** Water Resources Res. 1: 115-124.

An analysis was made to determine the amount of annual and seasonal water yield, flow duration, and peak flow frequency for seven major physiographic units in the Northeast. All watersheds (137) in the Northeast that were less than 100 square miles in area, that had continuous records from 1940 to 1957, and that were not appreciably affected by regulation and diversion were included in the analysis. In addition, streamflows of four small forested experimental watersheds were compared with average streamflow values of the physiographic units in which they were located. The longest simultaneous record available was for a 3-year period from 1959 to 1962. Results indicate significant differences in water yield between physiographic units as well as between watersheds within units. Water yields from the small experimental watersheds, although based on a shorter and different period of time, were found to correspond closely with average water yields of their respective physiographic units.

(115) Stewart, Guy Robertson. 1933. **A study of soil changes associated with the transition from fertile hardwood forest land to pasture types of decreasing fertility.** Ecol. Monog. 3: 107-145.

Typical soil conditions associated with the growth of hardwood forest, pasture grasses, and moss and fern were investigated in central New York. Change from trees to grass resulted in a loss of permeability to water, smaller water-holding capacity, and lessened air space. Forest soils and better pasture types had significantly deeper A and B horizons than did

the poor grazing land, or the moss and fern areas. Root growth of better pasture grasses was more extensive than that of the poorer. Forest soils possessed the highest initial content of nitrates. Kentucky blue grass soils had the highest level of mineral nutrients.

(116) Stickel, Paul W. 1933. **Relation of forests to the evaporating power of the air.** Jour. New England Waterworks Assoc. 47: 229-238.

Average monthly evaporation from Livingston atmometers at four locations in the Northeast from April to October was 1.3 to 1.8 times greater in the open than in the forest. Average temperatures in the duff layer ranged from 11 to 24° F. lower than soil-surface temperatures in the open, and in the 1-inch soil layer below the duff from 4 to 10° F. lower than a similar exposure in the open.

(117) Storey, Herbert C. 1949. **A year's progress at the Delaware-Lehigh Experimental Forest.** INCODEL Annual Meeting. U. S. Forest Serv. Northeast. Forest Expt. Sta., 10 pp., mimeo.

During the first year of study, the principal effort was establishment of streamflow, groundwater, climate, and soil-moisture installations and beginning of record collection. A topographic survey is underway and a geologic survey completed. Studies of soil freezing have been started, and some 200 plots have been prepared and planted to 10 different tree species to determine which species are best suited to scrub oak areas. An interception study will be started and soil and vegetation surveys will be made.

(118) Storey, Herbert C. 1949. **Watershed research in the Delaware and Lehigh.** Pa. Forest Leaves 34: 15-16.

Watershed-management problems in the Northeast involve increasing supplies of good water, regulating flow, and improving quality under more intensive land use. Research by the Northeastern Station has begun at the Delaware-Lehigh Experimental Forest, Monroe County, Pennsylvania, on an 1,800-acre scrub-oak watershed. Objectives are to determine the water relations of scrub oak, to find the best method for converting scrub oak to commercial timber, and to measure the effects of this conversion on water relations. Streamflow and climatic instruments have been installed, soil-moisture studies have been initiated, and groundwater observation wells have been drilled.

*(119) Storey, Herbert C. 1951. **Forest and water research project.** Delaware-Lehigh Experimental Forest. Pa. Dept. of Forests and Waters. 44 pp., illus. Harrisburg.

A cooperative forest and water research project was started at the Delaware-Lehigh Experimental Forest in eastern Pennsylvania in 1948. Forest-management (scrub-oak conversion) and watershed studies are described, and other studies planned are outlined. Daily discharge of Dilldown Creek, groundwater elevations, climatic measurements, and other hydrologic data are given for the period October 1948 to September 1950.

(120) Storey, Herbert C. 1954. **Water problems and watershed management.** Pa. Forests 44: 60-62, 70-73, illus.

Watershed management plays an important part in solving problems of

water shortages, floods, and water quality. Defined as the establishment and carrying out of measures and practices intended to attain certain desired characteristics of water yield from a watershed, watershed management requires positive steps to accomplish a specific objective. This requires quantitative knowledge of the relationships of vegetation, soils, and water, the hydrologic cycles, interception of rainfall and snow, infiltration, soil freezing, and other factors. The Northeastern Station is carrying out soil-plant-water relations studies in Pennsylvania and West Virginia, and region-wide a study of snow and frost depths in relation to forest cover.

(121) Storey, Herbert C., W. E. McQuilkin, and Eugene McNamara. 1953. Report No. 2: **Forest and Water Research Project, Delaware-Lehigh Experimental Forest.** Pa. Dept. Forests and Waters. 48 pp., illus. Harrisburg.

Progress report on studies on the Delaware-Lehigh Experimental Forest in Pennsylvania, including scrub-oak conversion and watershed studies. Planting results are reviewed and results of direct-seeding and natural-regeneration studies are described. Detailed studies of soil and vegetation have been made on the gaged watershed. Streamflow and climatic measurements are summarized, and estimations of evapotranspiration and of the water balance are discussed. Daily streamflow, groundwater, climate, soil-moisture and other hydrologic data are given for the period October 1950 to September 1952.

*(122) Sushko, Walter C., and Irvin C. Reigner. 1961. **A city manages its forested watershed lands.** Jour. Soil and Water Conserv. 16: 119-122, illus.

The city of Baltimore manages 17,300 acres of watershed lands, mostly forested, that surround three water-supply reservoirs. Water-supply protection measures include reforestation of idle land, careful location and drainage of logging roads and revegetation of steep grades following logging, and close supervision of recreation. Streamflow from three small experimental watersheds is being gaged to determine the effect of forest treatment on water yield.

(123) Trimble, George R., Jr. 1952. **A method of measuring increase in soil depth and water-storage capacity due to forest management.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 47. 8 pp.

Depth and water-storage capacity of shallow forest soils can be increased through forest management that maintains well-stocked stands. As examples, organic-matter content and pore space are given for soils found under three different forest-stand conditions. Soil in a well-stocked older stand of mixed hardwoods was 0.339 inch deeper than soil in a young understocked stand and 0.655 inch deeper than soil in a grazed stand.

(124) Trimble, G. R., Jr. 1954. **Forests are important on the watershed.** W. Va. Conserv. 18: 3-7, illus.

A review of watershed-research objectives and programs at the Fernow Experimental Forest. Relationships of forest cover to water quality are discussed, and logging methods and equipment that protect water values are recommended.

(125) Trimble, George R., Jr. 1955. **Watershed research begins in New Hampshire.** N. H. Forest Notes 46: 22-25, illus.

Outlines the water problems of New Hampshire and describes the watershed-management research project begun by the U. S. Forest Service on the 7,500-acre Hubbard Brook Experimental Forest near West Thornton, N. H.

(126) Trimble, George R., Jr. 1959. **A problem analysis and program for watershed-management research in the White Mountains of New Hampshire.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 116. 46 pp. illus.

A long-range forest watershed-research program is described that is centered on the Hubbard Brook Experimental Forest where the effects of forests on streamflow are being studied. Problems of water quality and water quantity are discussed. Forest hydrologic processes that affect the distribution of precipitation are described in respect to their importance, status of present knowledge, deficiencies in knowledge, and types of studies needed. Finally, a program of water-quality and -quantity studies is given and priorities are considered.

(127) Trimble, George R., Jr. 1959. **Logging roads in Northeastern municipal watersheds.** Jour. Amer. Water Works Assoc. 51: 407-410.

Because of erosion and sedimentation hazards, logging of municipal watersheds has often been considered risky. Sedimentation hazards may be practically eliminated if the location, construction, and maintenance of logging roads are in accordance with recommendations developed from watershed research. Recommendations are given for reducing erosion from road surfaces and adjacent disturbed areas and for preventing eroded materials from reaching the stream course. Close supervision of the logging operations is necessary.

(128) Trimble, G. R., Jr. 1961. **Water management. One of the multiple uses of forest land.** Va. Tech. Forester 13: 17-21.

Multiple-use management of forest land involves consideration of the water resources because water supplies and water quality are affected by forest cutting practices. Water-quality control involves reducing erosion from disturbed areas, and keeping eroded material out of streams; these are illustrated by recommended methods for locating and constructing logging roads.

(129) Trimble, George R., Jr. 1962. **Good and bad in logging.** Northeastern Logger 11(3): 18, illus.

Two photographs taken in West Virginia are compared, a picture of a horse-logging operation with skid trails running straight up-and-down hill and a picture of a contour logging-road system. In the former, skid trails averaged 51 percent in grade with centers about 45 feet apart. Twelve percent of the area was severely eroded. Contour logging reduced erosion and left the roads in good condition for future operations.

(130) Trimble, G. R., Jr. 1963. **Watershed management research.** Amer. Pulpwood Assoc. Tech. Paper 63-P-3. 6 pp.

Forest watershed research in Appalachia is conducted at the Coweeta

Hydrologic Laboratory in western North Carolina, at the Timber and Watershed Laboratory at Parsons, W. Va., and at The Pennsylvania State University, University Park, Pa. The nature of the research on water yield and quality problems is described and some results are given.

*(131) Trimble, G. R., Jr., and Burley D. Fridley. 1963. **13 years of forestry research in West Virginia.** U. S. Forest Serv. Res. Paper NE-5, 55 pp., illus. Northeast. Forest Expt. Sta., Upper Darby, Pa.

A progress report on the activities and accomplishments of the field unit of the Northeastern Forest Experiment Station established at Elkins, W. Va., in 1948 to conduct research in timber and watershed management in the northern Appalachian Mountain region.

(132) Trimble, George R., Jr., Charles E. Hale, and H. Spencer Potter. 1951. **Effect of soil and cover conditions on soil-water relationships.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 39. 44 pp., illus, Upper Darby, Pa.

Soil samples were taken from representative parts of the Allegheny River watershed to find out how soil condition and land use affect movement and storage of water in the soil. Percolation rates, detention storage, retention storage, and transmission rates and capacities were determined and analyzed in relation to soil characteristics and land use. Physical soil improvements resulting from better land-management practices were greatest in the upper soil horizons. Major factors that affect soil-water relationships on forest lands are grazing, drainage conditions, and humus type. Correlations and regressions were developed between volume weight and organic content, percolation rate and detention storage, detention storage and organic content, and detention storage and volume weight.

(133) Trimble, G. R., Jr., and Howard W. Lull. 1956. **The role of forest humus in watershed management in New England.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 85. 34 pp., illus.

Watershed functions of forest humus involve its effect on infiltration and percolation, water storage, and evaporation. These reflect its physical properties. In the Northeast, depth of hardwood humus ranges from 2 to 5 inches, with water-storage capacities of 0.5 to 2.0 inches. Conifer humus varies between 3 and 6 inches with storage of 1 to 2.5 inches. Conifer humus accumulates at the rate of about ⅔ inch every 10 years, hardwoods on medium-texture soil ¾ inch, and on coarser soil ¼ inch. Major gaps in our knowledge of humus are listed.

(134) Trimble, George R., Jr., K. G. Reinhart, and Henry H. Webster. 1963. **Cutting the forests to increase water yields.** Jour. Forestry 61: 635-640.

Watershed-research results in West Virginia indicate that the cost of increasing water yields by clearcutting, based on loss in timber income and cost of treatment, is about 4 cents per 1,000 gallons. Effects of cutting on peak flows and water quality are also discussed.

*(135) Trimble, George R., Jr., and Richard S. Sartz. 1957. **How far from a stream should a logging road be located?** Jour. Forestry 55: 339-341, illus.

Based on studies made in the White Mountains of New Hampshire, the rule of thumb for determining how wide a filter strip is needed along logging roads to keep sediment from getting into streams: starting with a strip 25 feet wide on level land, the width of the strip should increase 2 feet for each 1 percent increase in slope of land between road and stream. For municipal watersheds the safety factors are doubled.

*(136) Trimble, George R., Jr., Richard S. Sartz, and Robert S. Pierce. 1958. **How type of soil frost affects infiltration.** Jour. Soil and Water Conserv. 13: 81-82.

Ring-infiltration tests in New Hampshire showed that concrete frost in open ground is impermeable, whereas in forest land frost is permeated by root holes and animal burrows that offer passageway to surface runoff. Granular frost was more permeable than unfrozen soil.

(137) Trimble, George R., Jr., and Sidney Weitzman. 1953. **Soil erosion on logging roads.** Soil Sci. Soc. Amer. Proc. 17: 152-154.

Erosion from logging roads in mountainous West Virginia was measured before, during, and after logging. Erosion was found to be related to grade, length of slope, intensity of use, vegetation, soil, and climate. First-year erosion from logging roads ranged from 0.4 to 1.2 inches depending on grade and slope length. Erosion was much greater on heavily used than lightly used skid roads, and much greater during skidding than after skidding. On some roads formation of a rock pavement stopped erosion.

*(138) Trimble, G. R., Jr., and Sidney Weitzman. 1954. **Effect of a hardwood forest canopy on rainfall intensities.** Amer. Geophys. Union Trans. 35: 226-234, illus.

Ground rainfall intensities and throughfall were measured under a fully stocked hardwood stand in West Virginia for 1 year. Maximum 5- and 15-minute intensities were compared with similar measurements made in the open. The study showed that low rain intensities (below 0.5 in./hr.) are reduced more by summer canopy, and higher intensities (above 0.5 in./hr.) are reduced more by winter canopy. Throughfall is about the same in both winter and summer. The authors conclude that forest cover has only a limited value in reducing the erosion potential of rainfall as it strikes the forest floor. Litter and humus provide the necessary protection.

(139) Trimble, G. R., Jr., and Sidney Weitzman. 1956. **Chaff seeding—one answer to soil washing on logging roads.** W. Va. Conserv. 19 (12): 12-13, illus.

Chaff from farm harvesting operations, spread over skidroads and log decks, and limed and fertilized, proved effective for stabilizing disturbed areas that otherwise might have eroded. Two years after treatment the road seeded, limed, and fertilized was 76 percent covered by vegetation; the road seeded only, 51 percent; and the road with no treatment, 28 percent.

(140) Trimble, George R., Jr., et al. 1957. **New Hampshire guides for logging roads and skid trails.** Univ. N. H. Ext. Serv. Ext. Folder 35. 4 pp., illus.

Practical guides for locating, constructing, and maintaining logging roads and skid trails for efficient logging, with emphasis on measures to prevent erosion and damage to the water resource.

(141) Tripp, Norman R., and Howard W. Lull. 1958. **Management problems and opportunities on forested watersheds in the Northeast.** Soc. Amer. Foresters Proc. 1957: 30-32.

Water problems are discussed in terms of population pressures, uncertain water supplies, inadequate reservoir storage, and water pollution. Lack of technical knowledge and a need to convince the public that management of land to assure reliable water supplies is a concern for all segments of the population are seen as obstacles to watershed management.

(142) Watts, L. F., E. N. Munns, W. R. Chapline, and Luther G. Schnur. 1933. **A watershed protection program.** *In* **A national plan for American forestry.** 73d Cong. 1st Sess. Sen. Doc. 12: 1509-1536.

Three-fourths of the total forest area in the United States has major or moderate influence on watershed values; about two-thirds of this exerts a major influence, one-third a moderate. Watershed condition is determined principally by land ownership, the most acute streamflow and erosion problems existing on private lands. Major critical watershed conditions are described for 11 areas. A program for adequate watershed protection includes improved fire protection, the adoption to some degree of selective logging, reforestation of 11 million acres, grazing management, and other measures including research. Avenues of approach to the private-land problem include public cooperation with private owners, public regulation of private-land use, and public ownership of major-influence forest land.

*(143) Weitzman, Sidney. 1949. **The Fernow Experimental Forest.** U. S. Forest Serv. Northeast. Forest Expt. Sta. 16 pp., illus. Upper Darby, Pa.

The Fernow Forest of 3,640 acres of second-growth Appalachian hardwoods was set aside from the Monongahela National Forest for forest- and watershed-management research in northeastern West Virginia. The research program involves determination of the effects of forest cutting practices on timber volume, growth, and natural regeneration, and on quantity and quality of water supply; pilot-plant tests and demonstrations of timber-and-watershed-management practices; and collection of a complete set of records of quantity and quality yield of timber and water under management, and costs records. Climate, soils, and cover-types are described.

(144) Weitzman, Sidney. 1952. **Mountain log roads — design and construction.** W. Va. Conserv. 16(3): 16-21, illus.

In mountainous West Virginia the customary practice is to run logging roads straight up and down hill, which results in erosion and damage to watershed values. To avoid this, grades should be kept low by running the road slantwise up the mountainside and by using switchbacks. Roads

are located by using maps, aerial photos, and ground reconnaissance. The road should be constructed from the top of the mountain down. Water bars and grass seeding are important in preventing erosion. Advance planning gives the most economical road and one that will be usable for future operations.

*(145) Weitzman, Sidney. 1952. **Mountain logging.** South. Lumberman 185(2321): 199-202, illus.

Repeats material in West Virginia Conservation article described above and adds discussion of use of power saw, tractor, winch, and logging sulky. Logging-crew organization is also discussed.

(146) Weitzman, Sidney. 1953. **Five years of research on the Fernow Experimental Forest.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 61. 44 pp., illus.

A description of the Fernow Experimental Forest in West Virginia and its research aimed towards finding practical solutions to problems of managing timber and water resources. Results of timber-and-watershed-management compartment studies and special studies are outlined. Skid-road erosion and revegetation, truck roads and water quality, and the influence of the canopy on rainfall intensity are discussed.

(147) Weitzman, Sidney. 1954. **Forestry.** *In* **W. Va. Watershed Development Conf.** October 19-20, 1954, Proc.: 31-37.

In West Virginia demands for water for industrial and domestic use are increasing, stream pollution and sedimentation are serious problems, and floods cause great damage. These problems are accentuated by the present poor hydrologic condition of the forest land due to poor logging methods, grazing, and fire. Measures needed to solve these problems include improved cutting practices and logging methods, elimination of woodland grazing, intensification of fire control, reforestation, and strengthened timber and watershed research.

(148) Weitzman, Sidney. 1954. **Why we need watershed research in West Virginia.** W. Va. Conserv. 17(12): 4-7, illus.

In West Virginia, demands for water supply are increasing, and shortages threaten. Excessive stream fluctuations, sedimentation, heavy pollution, and floods indicate a growing problem. Some problems could be remedied by direct engineering action; others will take more time, since research is needed to find practical and economic answers.

(149) Weitzman, Sidney, and Kenneth G. Reinhart. 1957. **Water yields from small forested watersheds.** Jour. Soil and Water Conserv. 12: 56-59, illus.

Rainfall-streamflow records on the Fernow Experimental Forest in West Virginia provide an example of how such data can be used to estimate available streamflow for areas of similar vegetation, soils, and climate for a city water supply, or a site for an industry, or a pond. As a theoretical problem, water requirements of a small industry are analyzed.

*(150) Weitzman, Sidney, and G. R. Trimble, Jr. 1952. **Skid-road erosion can be reduced.** Jour. Soil and Water Conserv. 7: 122-124, illus.

On an experimental logging job in West Virginia, erosion was measured

from four kinds of skidroads that varied in slope, length per unit area, and water-bar installation. Erosion during the first year of operation ranged from 52 to 91 cubic feet per 100 feet and from 275 to 2,165 cubic feet for the total road length. Erosion from skidroads can be controlled by planning an efficient skidroad system that reduces mileage, avoids steep gradients, and provides simple water bars to keep the road drained.

*(151) Weitzman, Sidney, and G. R. Trimble, Jr. 1955. **Integrating timber and watershed management in mountain areas.** Jour. Soil and Water Conserv. 10: 70-75, illus.

Since forests cover two-thirds of the Appalachian Mountain area, water problems are closely tied up with the use made of forest land. Uses for water and wood products must be integrated and compatible with limitations imposed on an area by soils, climate, and topography. Results from the Fernow Experimental Forest indicate that commercial forest land may be managed to supply both timber and good water. Recommendations on methods of logging that will be helpful in protecting watershed values include a planned road system, low grades, shortened skidding period, logging road maintenance, and proper equipment. These recommendations have proved economically sound in practice.

*(152) Whelan, Donald E. 1950. **A method of evaluating the hydrologic effects of land use on large watersheds.** Trans. Amer. Geophys. Union 31: 253-261, illus.

To determine the effect of land use on flood runoff the total flood hydrograph is subdivided into separate hydrographs for surface, subsurface, and groundwater runoff. A unit hydrograph is then derived by considering surface and subsurface runoff contributing simultaneously by unit time periods. The total flood hydrograph as modified by a corrective land-use program is computed by using the derived unit hydrograph, groundwater relations, and infiltration rates of soil-cover complexes under the modified program. The method is applied to two flood hydrographs of the Baker River in the Merrimack watershed.

(153) Whelan, Donald E., Lemuel E. Miller, and John B. Cavallero. 1952. **A method of determining surface runoff by "routing" infiltrated water through the soil profiles.** U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 54. 15 pp., illus., Upper Darby, Pa.

Infiltration on a watershed basis was calculated by routing infiltrated water through the soil profile. Soil water storage and movement were determined from measurements of percolation rate, transmission velocities, and retention and detention storage volume for each horizon of principal soil-cover complexes. Percolation rates were adjusted to give the volume of surface runoff determined from the streamflow hydrograph. A sample routing is given. This method can be used to evaluate the effects of a land-use program on runoff.

(154) Wood, O. M. 1933. **Litter cover and soil surface temperatures, oak-pine type.** U. S. Forest Serv. Allegheny Forest Expt. Sta. Tech. Note 3. 1 p.

From July 5 until September 17, 1932, mean daily maximum temperatures at the soil surface within an 80-year-old stand of oak-pine was 81° F.

under oak leaves, 91° under black mulch paper, and 96° with no cover. There was no direct relation to daily maximum air temperature.

(155) Wood, O. M. 1935. **Forest removal affects local climate and growing conditions.** U. S. Dept. Agr. Yearbook 1935: 206-208.

A comparison of light-intensity conditions, soil-surface temperatures, evaporation, soil-moisture content, wind movement, and minimum air temperatures in the forest and in the open suggests that partial cutting is better than clearcutting because the resulting change in local climate is less severe.

(156) Wood, O. M. 1937. **The interception of precipitation in an oak-pine forest.** Ecology 18: 251-254.

Four rain gages set up in a mixed forest of oak and pine in New Jersey were read following 145 storms during a period of 17 months. Total precipitation ranged from 85 to 91 percent of the catch in a gage in the open. The proportion of rain reaching the ground in the woods increased with intensity and duration of storm. A statistically significant difference among the gages in the woods indicated that too few gages had been used.

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Storey, Herbert C.: 17, 19, 28, 29.
Sushko, Walter C.: 22, 29.
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Weitzman, Sidney: 6, 32, 33, 34, 35.
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Wood, O. M.: 35, 36.

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The Cost of SCALING & GRADING Hardwood Sawlogs

by Thomas W. Church, Jr.

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Foreword

HUNDREDS of articles have been written about log grading. Many of them extol the economic benefits that should accrue from the use of a log-grading system. Some lumbermen have heeded this advice and now use log grades to control the quality or species of logs delivered to their sawmills. Rarely, however, do these sawmill operators use a grading system that will provide an accurate estimate of lumber yield and quality. They think it would be too complex and too costly.

The purpose of this study reported here was to investigate one of these objections: the purportedly high cost of using a detailed grading system such as the U. S. Forest Service log grades. No published information was available, so it was necessary for us to investigate certain factors that we believed would have an important effect upon log-grading costs. Our study was designed to show how grading location, log size, crew size, and species influence both scaling and grading costs.

This paper describes experimental results and interprets these findings in terms of a practical application on Appalachian lumbering operations. All reference to statistical analytical procedures has been omitted from the text. However, scientifically oriented readers might be interested to know that results are based upon computer-programed regression techniques.

Since the basic sampling unit was 1,000 board feet gross log scale, Scribner rule, all results are reported in terms of this volume unit. To give you some measure of data variation: 9 times out of 10, the mean costs of scaling plus grading were within 10c per 1,000 board feet of the tabulated results. There was even less variation when grading costs were considered separately. In fact, for the same degree of confidence, average log-grading costs were within 2c per 1,000 board feet of the costs reported in the tables.

The Cost of SCALING & GRADING Hardwood Sawlogs

by Thomas W. Church, Jr.

The Author

THOMAS W. CHURCH, JR. joined the Forest Service's Northeastern Forest Experiment Station in 1946, after graduation from the Pennsylvania State University School of Forestry. He left the Station in 1955 to take a position with Whitney Industries, Inc., Sabattis, New York, in their forestry department. After 3 years in private industry he returned to the Forest Service and a position with the Lake States Forest Experiment Station. In 1964 he transferred back to the Northeastern Forest Experiment Station and to his present job at the Forest Products Marketing Laboratory in Princeton, West Virginia. Mr. Church has a Master's degree in forest utilization from Duke University.

WHY NOT GRADE LOGS?

"WHAT would it actually cost me to grade my sawlogs?" This question is frequently asked by many lumbermen who understand the benefits of log grading but have not yet adopted a log-grading procedure. If these lumbermen knew that they could grade logs for as little as 25c per 1,000 board feet, they might be induced to adopt log-grading procedures.

Can logs be graded accurately for only 25c per 1,000? They certainly can. At many mills they can be graded for as little as 15c per 1,000 board feet. Of course grading costs depend upon the daily volume of logs graded, the size of the logs graded, and the skill and efficiency of the grader.

If there are 10 logs per 1,000 board feet, an experienced man can grade this volume in about 3 minutes. This is about four times faster than he could scale these same logs if he followed the detailed scaling procedures used by the U. S. Forest Service. He is able to grade this rapidly because scaling and grading are logically performed as an integral operation, and grading requires many of the same measurements that are used for scaling. Therefore grading is faster than scaling because a log may be partially or completely graded by the time it is scaled.

Log grades provide the raw-material quality control needed by most hardwood lumbermen. This has been repeatedly emphasized by such authorities as Carpenter (1953) and Lockard (1950). Furthermore, the advantages of using log grades, the techniques

of applying them, and the results of actual log-grading tests have been reported in more than 250 publications prior to 1955. Yet many sawmill operators still buy logs on a rudimentary grading system or by casual inspection alone. Why hasn't the Forest Service log-grading system been adopted?

Complex log-grading systems are rarely used: they are too costly and too difficult for loggers to understand. These are the reasons most frequently given when lumbermen are asked why they do not use a detailed grading system of proven accuracy. Many sawmill operators might prefer to use a precise grading system for factory logs such as the one developed by the U. S. Forest Products Laboratory (1953). But they believe that application of these complicated grade specifications would require extra men and thereby would increase total operating costs. Furthermore, they feel that log suppliers who do not understand the grading rules might believe that they are being cheated; and thus these suppliers might send their logs to nearby competitors who use simplified grades or none at all.

These objections are valid and must be faced by an operator who is considering the adoption of a detailed log-grading system. Problems related to the interpretation and understanding of a grading system can best be solved by a training program in which both log suppliers and log purchasers participate. But problems associated with grading costs are most appropriately attacked through a research study.

THE STUDY

In the fall of 1964, the Forest Products Marketing Laboratory began a study of log-grading costs in the Appalachian Mountain region. Nine companies in West Virginia, one in Tennessee, one in North Carolina, one in Massachusetts, and one in Vermont cooperated with the Laboratory in the study. Records were taken for most of the major species of northern hardwoods and Appalachian hardwoods.

The primary objective of this study was to evaluate major factors that might affect the economics of scaling and grading hardwood

sawlogs. The four factors selected for evaluation were: (1) scaling and grading location, (2) log size, (3) grading-crew organization, and (4) species. Each of these variables was tested to determine its effect upon the time and cost of scaling and/or grading.

Although this study was designed primarily to investigate grading costs, scaling costs were also considered. Scaling and grading are normally performed as an integral operation because measurements of log size and the determination of scale defects have a direct effect upon log grade and quality. Therefore, in this study evaluations were made for grading costs and for scaling and grading costs combined.

METHODS

All log-grade determinations were based on the grading system developed by the Forest Products Laboratory (1953). This system, adopted by the U. S. Forest Service as standard for hardwood factory logs, provides for volume and value estimates by species, log grade, lumber grade, and average log diameter. Recommended grading procedures were followed precisely in order to develop accurate time and cost data.

Logs were scaled according to the rules outlined in the National Forest Scaling Handbook (1964). Thus average scaling diameter was obtained from at least two measurements at the small end of the log, and net volumes were computed from scale deductions for both surface and internal defects. Tabular deductions for internal cull and sweep were posted on our scale sticks to facilitate net scale determinations. Even with these short cuts, we found that scaling took considerably longer than grading.

Some of the items used for grade evaluation such as log size, percentage of cull, and percentage of sweep were obtained from the log-scale measurements. So scaling actually provided some of the information needed for grading. If log grading were performed as a separate operation and not combined with scaling, then the time and cost of grading might be greater than the values reported in this paper.

Scaling and/or grading costs are based on an assumed hourly wage cost of $2.50 for a skilled scaler and grader. In addition to wages, this figure includes employer's payments for unemployment compensation, payroll taxes, and health and accident benefits. This cost is higher than many lumbermen may presently be willing to pay. But these are technical services that directly affect profit and loss, so we believe that this wage charge is not at all unreasonable.

Since our objective was to obtain scaling and grading costs per 1,000 board feet, we first had to measure time and then convert time to cost. Measurements of scaling and grading performance were made for 1,000-board-foot units on a Scribner-log-rule basis. Rarely did any of our 338 sample units scale 1,000 board feet. Therefore, in summarizing the field measurements, we adjusted all scaling and grading times to a 1,000-board-foot basis.

We recorded scaling plus grading time in man-minutes for each 1,000-board-foot unit. Total elapsed time for each sample unit included all scaling and grading activities plus any nonproductive time for walking between logs, staying clear of moving equipment, and other short-term delays. This total elapsed time did not include long-term delays due to equipment breakdowns or lack of sufficient logs to complete the sample unit.

Grading time was recorded by stop watch. It included the following operations: recognition, measurement, and assessment of log surface and end features affecting log quality; turning the log when necessary to determine the grading face; and consideration of such quality-controlling factors as diameter and sweep, which were calculated while scaling.

The variables tested in this study were as follows:

A. Grading location:
1. In the woods. (a) At the stump. (b) At the landing.
2. At the sawmill. (a) In the log yard. (b) On the mill deck.

B. Log size:
1. Average scaling diameter per unit.
2. Number of logs per 1,000 board feet.

C. Crew organization:
1. One man.
2. Two men.

D. Species:

1. Individual species: (a) Red oak, *Quercus rubra* L.; (b) White oak, *Quercus alba* L.; (c) Chestnut oak, *Quercus prinus* L.; (d) Beech, *Fagus grandifolia* Ehrh.

2. Species group: (a) Sugar maple, *Acer saccharum* Marsh, and Red maple, *Acer rubrum* L.; (b) Yellow birch, *Betula alleghaniensis* Britton, and Sweet birch, *Betula lenta* L.; (c) White ash, *Fraxinus americana* L.; and American basswood, *Tilia americana* L.; (d) Yellow-poplar, *Liriodendron tulipifera* L.; and Cucumbertree, *Magnolia accuminata* L.; and (e) Other hardwoods.

RESULTS

Minimum Scaling and Grading Costs

Records from nearly 350,000 board feet of logs showed that one man can scale and grade 1,000 board feet of logs in about 15 minutes. Approximately 3 minutes, or 20 percent of this time, was spent on actual grading. The remainder was needed for scaling, recording the scale and grade in the tally book and on the logs, walking between logs, and minor nonproductive actions. At this rate, a man could scale and grade 32,000 board feet per 8-hour day at a cost of 62½c per 1,000 board feet. (Cost based on wage charge of $2.50 per hour.) The actual cost of grading would be only 12½c per 1,000.

Can a man keep up this pace all day and still apply the scale and grade specifications accurately? We found that he could. In fact, his efficiency should improve with increased experience because the results reported in this study are based upon the performance of trained men who had only a few months of practical experience.

Practical Scaling and Grading Costs

The scaling and grading costs mentioned in the preceding section are based on the assumption that a trained man is employed to perform these services. But the costs apply for only two situations: (1) where the scaler-grader constantly works to his maximum capacity of about 32,000 board feet per day, or (2) where

scaling and grading costs are charged as an expense item only for the time spent on these tasks.

Since most Appalachian sawmills cut less than 32,000 board feet per day, it is apparent that an experienced grader would not be busy all day. The question then arises, should a sawmill manager compute his scaling and grading charges per 1,000 board feet on the basis of the time actually spent appraising this volume, or should he base his unit scaling and grading costs upon the total daily wage cost regardless of the volume handled? We believe the latter alternative is the most reasonable method for computing unit scaling and grading costs even though it may not be a proper accounting procedure.

To substantiate this belief, let us assume that a sawmill owner decides to adopt the Forest Service scaling and grading system. He hires a technically trained man for this work and pays $2.50 per hour or $20 per day for these services. His sawmill produces about 16,000 board feet per day, so his average daily log receipts would be similar. Since the log grader can scale and grade this volume in about 4 hours, he would have half a day for other productive work.

But what other duties could this technician perform? The sawmill was probably efficiently staffed before he was hired, and certainly he would not be expected to perform menial odd jobs around the plant. Furthermore, log trucks do not arrive at regular intervals and the grader must always be ready to appraise logs as soon as they are delivered, or the mill yard will become cluttered. If the grader has other duties, these will have to be postponed while the logs are scaled and graded. These interruptions may seriously hinder the orderly sequence of production at the mill.

For these reasons, it is logical to expect that the grader will have only one assignment — to scale and grade the logs. Although he will not constantly be performing his assigned duties, his wages will continue regardless of the volume handled. Where this occurs, the sawmill operator should realize that his scaling and grading costs are influenced solely by the volume measured and appraised. Thus, the daily volume of logs available for scaling and grading significantly affects the cost of scaling and grading, as

shown in the following tabulation:

Daily volume scaled and graded (1,000 board feet)	*Scaling and grading cost per 1,000 board feet*[1]
8	$2.50
10	2.00
15	1.33
20	1.00
25	.80
30	.67

[1] Based on a total wage cost of $2.50 per hour or $20 per 8-hour day.

Grading Costs

Our observations showed that grading required 14 to 30 percent of the total time spent for both scaling plus grading. This wide range in grading time was due to difference in log size and grading location. Average grading time was 22 percent of the total scaling plus grading time. At this rate, the grading costs for many Appalachian mills would range from 15c to 55c per 1,000 board feet depending upon daily production rate. For an average mill sawing 15,000 board feet per day, the extra job of log grading would cost only 29c per 1,000 board feet.

The adoption and application of a detailed log-grading system will have little effect upon the quality of logs delivered to a mill unless there are economic benefits to both log producer and log consumer. Of course, the use of a log-grading system will not change sawlog quality. However, when prices for graded logs are commensurate with log value, the use of a grading system should affect the quality of logs delivered to a mill. Therefore, if log quality is to be improved by increasing the proportion of higher grade logs, then log prices will also have to be increased to compensate the log supplier for the unsalable logs and the cost of sorting.

Location

The place at which scaling and grading was performed had little effect upon the time and cost of these combined functions when performed by a one-man crew. It was least expensive to scale and grade on the sawmill deck and most expensive at the

stump. There was almost no difference in cost between the mill yard and the landing. For a two-man crew, however, there was a substantial difference in cost between both the stump and landing and the other two locations. The following tabulation, based on average costs for all log sizes, shows these differences in scaling and grading cost per 1,000 board feet:

Location	*One-man crew*	*Two-man crew*
Stump	$0.62	$1.37
Landing	.58	1.11
Yard	.59	.95
Deck	.52	.97

Location had even less influence upon grading costs than it had upon the combined costs of scaling and grading. Among the four locations examined in this study, there was a difference in average grading costs of only 2c per 1,000 board feet for a one-man crew and 5c per 1,000 board feet for a two-man crew. Thus, location had an insignificant effect upon grading cost — especially when all log sizes and species were grouped.

Of course these results are based on our experimental techniques, in which log volume at any location was assumed to be unlimited. In actual practice, we believe it will be considerably less costly to scale and grade at the mill than in the woods. Not only are more logs available at the mill than at any woods landing, but they are more easily and safely scaled and graded. Rarely will any sawmill receive all its logs from one source: therefore logs can be scaled and graded more cheaply at the mill than at the landings or the stump because only one scaler-grader is needed.

Should logs ever be graded and sorted at the landing so that logs of various quality may be loaded and trucked directly to mills processing a specific grade? Yes — but only where one scaler-grader is needed to evaluate the total daily log requirements of any one mill. If more than one scaler-grader is needed to service several landings, then it may be cheaper to haul all grades to the principal sawmill. Of course, both the question posed and the answer provided assume that there are separate market outlets for different grades of hardwood sawlogs. At present such diversification is extremely rare. If such a practice should become more

common, we believe that it would be more expensive to have extra graders at the landings than to truck all logs to the primary mill, grade them and then reload and haul the low-grade logs to a second mill. However, more research is needed to show what system would be most efficient.

Occasionally it may be advantageous to scale and grade at the landing. Some of the advantages may be indirect. Loggers would be more inclined to buck for the highest quality if a grader were stationed at the landing. In fact, the grader might even mark the location of the bucking cuts and thereby improve log quality. For some Appalachian lumbermen, however, it would be inadvisable to scale and grade at the landing. In rugged terrain, a grader will seldom evaluate log quality at more than one landing daily because as soon as tree lengths are bucked, they are pushed aside to make room for the next hitch of tree lengths or to allow passage of log trucks. Therefore more than one grader would be needed and costs would increase.

Although scaling and grading costs are least on the sawmill deck, we believe that the mill yard affords the most advantages (figs. 1 to 3). These advantages are (1) greater ease, safety, and accuracy of scaling and grading through use of mechanical log-handling equipment; (2) immediate scale and grade for trucker and log contractor as basis for weekly payment; (3) possible resale of low-grade factory logs to a local mill specializing in ties, timbers, and industrial products; (4) less noise, dust, and danger than on the sawmill deck; (5) greater opportunity for sawing efficiency when sorting and stacking by grade as well as by species; and (6) more efficiency than would be possible with woods scaling and grading because of the greater volume processed daily.

It is implied above that the use of mechanical log handling equipment would improve the efficiency and accuracy of log grading. No tests were made to prove this statement nor were any grading costs assigned for the use of this equipment. From our observations, some Appalachian sawmill operators have both the time and space to spread out the logs for better grading. In fact, one of our study cooperators uses this technique and is well pleased with it. Since he sorts each truck load and decks logs by

Figure 1.—Some companies scale logs on the truck. This practice is not advisable because the scaler must climb the load to make accurate diameter measurements. Furthermore, he cannot measure diameter or assess end defects of logs placed tight against the headboard. Grading logs on trucks is also inadvisable because important surface features are obscured and accurate quality evaluations cannot be made.

species, he is evidently unconcerned about the small extra cost of using this equipment to improve scaling and grading — especially since it does not delay any facet of his milling operation.

Log Size

Average log size had a significant but inverse affect upon scaling and grading costs. As average log size increased, scaling and grading cost per 1,000 board feet decreased. This relationship is quite credible because scaling and grading time per log is relatively constant regardless of log size or volume. Therefore, the larger the log, the fewer the number of logs per 1,000 board feet, and the lower the costs per unit of volume.

Number of logs per 1,000 board feet provided a better measure of scaling and grading costs than did average scaling diameter.

Figure 2. — Logs should be scaled and graded on the ground, where accurate volume and quality assessments can be made.

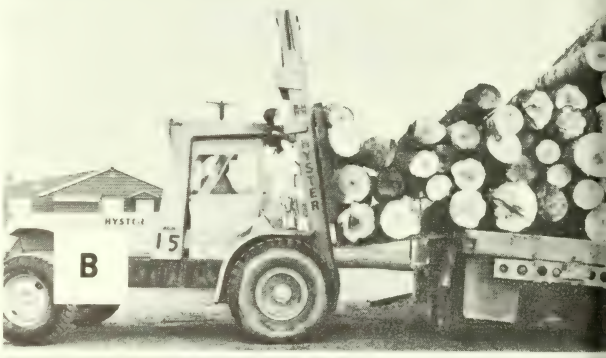

Figure 3.—Where space permits, logs should be spread out in the mill yard for accurate, safe, and economic scaling and grading. One company uses the following technique. (**A**) Lift truck forks are placed under the logs and the stakes are removed from one side of the truck. (**B**) As the lift truck backs up, the logs roll onto the forks. (**C**) The lift truck spreads the logs in an unobstructed yard area by tilting the forks forward and moving rapidly in reverse. (**D**) The logs are spaced for efficient scaling and grading and then are removed for sawing or decking.

This evaluation was substantiated by our statistical analysis. For nearly every combination of log size, crew size, and grading location, regressions based upon number of logs per 1,000 board feet gave more precise results than did regressions based upon scaling diameter. Some people may object to our practice of definitively equating log size with number of logs per 1,000 board feet. However, we believe this is both technically sound and desirable because the number of logs per unit of volume incorporates length as well as diameter.

Log size had a more pronounced effect upon scaling and grading costs at the stump than it did at the other locations tested (tables 1 and 3). Except for sampling units comprised of large logs, more time was required to scale and grade a 1,000 board-foot unit of logs in the woods because of the time spent walking between logs. In the woods, therefore, scaling and grading costs were influenced by the physical placement of the logs as well as by the average size of the logs.

For a one-man crew, log size had an even stronger influence upon grading costs than it did upon scaling plus grading costs. The same trends prevailed: grading costs increased with a concomitant increase in number of logs per unit of volume. At most

Table 1. — Effects of log size and location upon the time[1] and cost[2] of scaling and grading 1,000-board-foot units with a 1-man crew

Average log size (No. logs per 1,000 board feet)	Scaling and grading location							
	Stump		Landing		Yard		Deck	
	Time	Cost	Time	Cost	Time	Cost	Time	Cost
	Min.	*$*	*Min.*	*$*	*Min.*	*$*	*Min.*	*$*
6	8.8	0.37	10.2	0.42	9.2	0.38	10.1	0.42
8	12.5	.52	12.6	.52	12.4	.52	11.6	.48
9	14.4	.60	13.6	.57	13.9	.58	12.3	.51
10	16.2	.68	14.6	.61	15.0	.62	13.1	.54
11	18.0	.75	15.4	.64	16.1	.67	13.8	.57
12	19.8	.82	16.0	.67	17.1	.71	14.5	.60
14	23.6	.98	17.3	.72	18.4	.77	16.0	.67

[1] Based on elapsed clock time for 140 thousand-board-foot units at 11 companies in 6 states.
[2] Based on wage rate of $2.50 per hour.

Table 2. — Effects of log size and location upon the time[1] and cost[2] of grading 1,000-board-foot units with a 1-man crew

Average log size (No. logs per 1,000 board feet)	Grading location							
	Stump		Landing		Yard		Deck	
	Time	Cost	Time	Cost	Time	Cost	Time	Cost
	Min.	*$*	*Min.*	*$*	*Min.*	*$*	*Min.*	*$*
6	1.3	0.05	2.6	0.11	1.9	0.08	1.9	0.08
8	2.2	.09	3.1	.13	2.6	.11	2.6	.11
9	2.7	.11	3.3	.14	2.9	.12	3.0	.12
10	3.1	.13	3.4	.14	3.2	.13	3.3	.14
11	3.5	.15	3.5	.15	3.6	.15	3.7	.15
12	4.0	.17	3.5	.15	3.9	.16	4.0	.17
14	4.9	.20	3.5	.15	4.6	.19	4.8	.20

[1] Based on elapsed clock time for 140 thousand-board-foot units at 11 companies in 6 states.
[2] Based on wage rate of $2.50 per hour.

grading locations, the cost of grading a unit of 14 logs per 1,000 board feet was 2½ to 4 times greater than that for a unit of 6 logs per 1,000 board feet (table 2).

For a two-man crew, the effect of log size upon grading time was not so pronounced (table 4). In fact, log size had no influence on the rate at which a two-man crew could grade logs in the woods or on the sawmill deck. Evidently there were insufficient samples to show a trend.

None of the tables presented in this paper accurately illustrate the true effects of log size upon grading time. The tabular data are based on field samples and these 1,000 board-foot units are frequently a composite of widely different log sizes.

When log size and grading time are analyzed independent of random sample occurrence, a different pattern emerges. A 1,000-board-foot unit of logs measuring 8 to 10 inches in diameter can be graded just about as rapidly as a similar volume of logs measuring 23 inches in diameter or larger. This apparent anomaly is due to the grading specifications used: most logs under 11 inches are automatically grade 3 if they meet other broad standards of sweep, cull, and defect placement. Therefore it takes very little

time to grade them. But for logs 11 inches in diameter and larger, there are several possible grades and more specifications to consider; so grading immediately becomes more time-consuming. The relationship between log diameter and grading time are shown in the following tabulation:

Log diameter (inches)	*Grading time (man-minutes per 1,000 board feet)*
8-10	1.0
11-13	5.3
14-16	3.4
17-19	2.5
20-22	1.7
23+	1.1

Our observations showed that log size had one other obvious effect on grading costs, and this occurred solely at the landing. At the landing, there was only a slight increase in grading cost with a substantial increase in the number of logs per 1,000 board feet. In fact, there was no change in grading cost for samples with more than 11 logs per 1,000 board feet (table 2).

There is a logical explanation for this relationship. When tree lengths are skidded and bucked at the landing, the logs still occupy the same relative position that they had in the tree before

Table 3. — Effects of log size and location upon the time[1] and cost[2] of scaling and grading 1,000-board-foot units with a 2-man crew

Average log size (No. logs per 1,000 board feet)	Scaling and grading location							
	Stump		Landing		Yard		Deck	
	Time	Cost	Time	Cost	Time	Cost	Time	Cost
	Min.	*$*	*Min.*	*$*	*Min.*	*$*	*Min.*	*$*
6	24.5	1.02	17.9	0.75	16.1	0.67	18.5	0.77
8	29.5	1.23	23.8	.99	20.2	.84	21.3	.89
9	31.9	1.33	26.1	1.09	22.0	.92	22.8	.95
10	34.5	1.44	28.0	1.17	23.7	.99	24.0	1.00
11	36.8	1.53	29.3	1.22	25.3	1.05	25.5	1.06
12	39.3	1.64	30.3	1.26	26.7	1.11	26.9	1.12
14	44.2	1.84	30.7	1.28	29.1	1.21	29.8	1.24

[1] Based on elapsed clock time for 198 thousand-board-foot units at 7 companies in 4 states.
[2] Based on wage rate of $2.50 per hour.

Table 4. — Effects of log size and location upon the time[1] and cost[2] of grading 1,000-board-foot units with a 2-man crew

Average log size (No. logs per 1,000 board feet)	Grading location							
	Stump		Landing		Yard		Deck	
	Time	Cost	Time	Cost	Time	Cost	Time	Cost
	Min.	*$*	*Min.*	*$*	*Min.*	*$*	*Min.*	*$*
6	7.6	0.32	4.5	0.19	4.7	0.20	6.7	0.28
8	7.6	.32	6.5	.27	5.8	.24	6.7	.28
9	7.6	.32	7.2	.30	6.3	.26	6.7	.28
10	7.6	.32	7.9	.33	6.8	.28	6.7	.28
11	7.6	.32	8.3	.35	7.4	.31	6.7	.28
12	7.6	.32	8.6	.36	7.9	.33	6.7	.28
14	7.6	.32	8.6	.36	9.0	.38	6.7	.28

[1] Based on elapsed clock time for 198 thousand-board-foot units at 7 companies in 4 states.
[2] Based on wage rate of $2.50 per hour.

being bucked. The butt log is graded first, then the upper logs from the butt up. Both surface and internal defects found in the lower logs frequently recur in the upper logs of the same tree. This tendency for important log-grade characteristics — such as bumps, bird peck, stain, and seams — to occur in several logs of the same tree should make log grading faster and cheaper. However, at the landing, logs are frequently jammed together. In order to see more than 2 faces, it is often necessary to roll the log, and this is difficult and time-consuming because of space limitations and soil conditions. For this reason, any advantage of continuous tree grading at the landing is lost because of the extra time required to observe surface characteristics on hidden faces. Therefore differences in grading time due to log size are reduced because the bigger logs are more difficult to turn than the smaller logs.

Crew Size

We found that one man could scale and grade almost as rapidly as a two-man crew. Occasionally one man could scale and grade more volume than a two-man crew during the same elapsed time.

Thus scaling and grading cost per 1,000 board feet was considerably lower with a one-man crew than with a two-man crew. Tables 1 through 4 illustrate this: both the time and cost of scaling and/or grading with a two-man crew were higher than the corresponding time and cost for one man with comparable log sizes and grading locations.

Some companies employ a two-man scaling crew, and there are situations where such a crew functions more efficiently than a one-man crew. If logs are scaled in decks or in truck-load piles, two men are necessary because both ends of individual logs must be identified if the logs are to be scaled accurately (fig. 4). However, logs should not be graded in piles or decks: they should be exposed for proper evaluation of surface defects. Therefore the advantages of a two-man scaling crew do not apply to log grading.

The inefficiencies of our two-man scaling and grading crew in this study compared to our one-man crew may have been due to the operating procedures that we used. Although one man scaled while the other graded, each performed certain measurements and calculations that were mutually beneficial. For instance, both men measured log-end diameters simultaneously. The scaler immediately recorded gross volume while the grader measured the sweep or the scale defects that occurred on his end of the log. He conveyed this information to the scaler, who in turn gave the grader the measurements of any grade defects on the scaler's end of the log.

Each man then completed his task of scaling and grading. The grader usually finished first. He then waited for his partner so they could work together on the next log. This inactivity for one man increased the time and cost of scaling and grading with a two-man crew. Reorganization of task assignment might improve the performance of a two-man crew. But it is extremely doubtful that two men working as a crew can scale and grade as efficiently as one.

Species

Tree species did not significantly affect grading time. Differences in average grading time among the nine species tested did not

Figure 4.—When logs are scaled in piles or large decks, two men are needed for efficient and precise volume determination. However, logs cannot be accurately graded in these piles or decks because surface characteristics are obscured.

exceed 1 man-minute per 1,000 board feet. Thus, the variation in average grading cost due to species was less than 5 cents per 1,000.

When this study was designed, we thought that species might affect the time and cost of log grading because of inherent characteristics such as persistent limbiness and susceptibility to bird peck. But we found that species characteristics had very little effect: It was still necessary for us to scrutinize every log for obscure grade defects.

Of course, there were a few wider variations in grading time between species within a particular diameter class. But these deviations never exceeded 2 man-minutes per 1,000 board feet. In fact, within any of the six diameter classes tested, species grading times were uniform (table 5).

Table 5.—Average grading time by species and diameter class, in minutes per 1,000 board feet

Species	Diameter class — inches						Average all diameters[1]
	8-10	11-13	14-16	17-19	20-22	23+	
Red oak	0.9	5.3	3.3	2.6	1.7	0.8	3.0
White oak	1.6	5.2	2.8	1.8	1.9	1.5	2.3
Chestnut oak	.6	6.4	3.1	1.9	2.0	1.8	2.8
Beech	1.5	5.0	3.5	2.6	1.8	1.4	3.1
Birch	0	5.4	4.3	2.1	1.6	.5	3.2
Maple	1.2	5.5	3.8	2.7	1.9	1.4	3.3
Ash-basswood	1.6	5.7	3.2	2.1	1.6	.4	3.3
Poplar-cucumber	.8	4.6	3.0	2.3	1.0	0	3.0
Other hardwood	.3	5.0	3.5	2.7	1.2	1.1	3.3

[1] Averages based on grading time weighted by volume within each diameter class.

SUMMARY

Hardwood logs can be graded inexpensively without hindering either woods or sawmill production schedules. Grading costs for most Appalachian and New England lumbermen will range from 15c to 55c per 1,000 board feet, depending upon the volume graded daily. For daily production rates of 30,000 board feet and 8,000 board feet, the respective costs of scaling and grading will range from 67c to $2.50 per 1,000 board feet.

Detailed records from nearly 350,000 board feet of hardwood sawlogs indicate that for a sample of logs averaging 10 per 1,000 board feet, scaling and grading require about 15 man-minutes per 1,000 board feet. Grading requires about 20 percent of the total or 3 man-minutes per 1,000.

Both the time and cost of scaling and grading — assuming an unlimited log supply — are influenced by such factors as average log size and crew size. Scaling and grading costs for 1,000 board feet are 1½ to 2½ times greater for small logs averaging 14 per 1,000 board feet than they are for large logs averaging 6 per 1,000 board feet. Grading costs are 2½ to 4 times greater for the smaller logs except those below 11 inches in diameter. Crew size is also important: one man was found to be nearly twice as efficient as a two-man crew.

Under practical conditions representative of many Appalachian hardwood operations, a scaler-grader will rarely work up to his daily capacity of 32,000 board feet. Therefore, scaling and grading costs per 1,000 board feet are more a function of the daily volume processed than a function of log size. In this situation grading location is important because the volume scaled and graded is influenced by the quantity of logs available.

Although logs can be scaled and graded at lowest cost on the sawmill deck, this is not the best place to grade logs. A prerequisite for efficient grading is a location where a grader can see and handle logs in an unhurried atmosphere. We believe the mill yard offers the most advantages: (1) there is a greater concentration of logs than in the woods or at the landing; (2) there is an opportunity for sorting logs by grade and sawing or selling certain grades to improve sawmill efficiency; (3) there is less noise, confusion, and danger than on the sawmill deck; (4) there is usually room to temporarily disperse the logs for better visibility and more accurate grading; and (5) there is power equipment available to move the logs easily and safely for greater scaling and grading efficiency.

With daily log-appraisal costs fixed, the factors that have the greatest practical influence upon scaling and grading costs are: (1) the crew size and (2) the volume of logs available, as determined by location. Average log size is important only when the scaler-grader works close to his daily capacity. Species is unimportant because inherent tree characteristics have no significant influence upon the time and cost of grading.

■

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Field and laboratory investigations of *Bacillus thuringiensis* as a control agent for gypsy moth, *Porthetria dispar* (L.)

by Franklin B. Lewis
and Donald P. Connola

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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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Field and laboratory investigations of

Bacillus thuringiensis

as a control agent for gypsy moth

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NOTE: Mention of a particular commercial product in this paper should not be construed as an endorsement by the Forest Service or the U. S. Department of Agriculture.

Introduction

SUCCESSFUL control of the gypsy moth, *Porthetria dispar* (L.), has been a goal of entomologists in the northeastern United States for many years. When DDT came into use, and more efficient aerial-spraying methods were developed after World War II, this goal was apparently reached. However, a few years ago there arose a vehement public reaction against the use of chemical insecticides. This spurred new interest in the use of biotic methods for combatting insects, and much research is now centered on insect diseases and their possible uses in insect control.

Because disease is a primary factor in the population dynamics of the gypsy moth (Campbell 1963), disease-causing agents are biologically feasible as an alternative to DDT. Commercial preparations of a microbial insecticide, *Bacillus thuringiensis* var. *thuringiensis* Berliner (referred to from here on as *Bt*), have been available since the late 1950s for control of leaf-feeding lepidopterous pests.

To explore the possibilities of using *Bt* as a means to control the gypsy moth, a series of field and laboratory tests were begun in 1961 by the Northeastern Forest Experiment Station at its Forest Insect Laboratory at New Haven, Conn. This paper is a report on the techniques used in those tests.

Preliminary laboratory and field tests were conducted with a wettable powder formulation of *Bt* against the gypsy moth in 1961. Though the results were inconclusive in terms of practical control, considerable information and experience were gained in handling and evaluating this type of insecticidal material.

The necessity for adequate pre-testing of the material to be used in the field, and the necessity for special techniques for the proper assessment of spray deposit, became very apparent during the 1961 field test conducted in New York.[1] In addition, the development of special methods for evaluating the effects of the microbial insecticide was clearly demonstrated by this test.[2]

A larger-scale field test, using a *Bt* powder plus Lovo 192[3] as a sticker-anti-evaporant, was conducted in 1962. The powder was specially formulated without a wetting agent. This test, also carried out in New York State, was encouraging too; but the results were erratic, and operational difficulties again were encountered in mixing, storing, and applying the spray. Yet more information was obtained about the field techniques needed to properly evaluate the distribution and effects of the spray. Moreover, valuable information was obtained in corollary laboratory tests of the effects of *Bt* on the gypsy-moth larva.[4]

The development in late 1962 of a new emulsifiable liquid *Bt* concentrate appeared to alleviate the difficulties of mixing and applying the powder preparation, which had seriously limited the practical effectiveness of the 1961 and 1962 tests. This new formulation was field-tested in New York in 1963 with much better results.[5]

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[1] Lewis, F. B., D. P. Connola, and R. C. Sweet. FIELD TEST OF A BACILLUS THURINGIENSIS SPORE-CRYSTAL CONCENTRATE AGAINST THE GYPSY MOTH IN NEW YORK. U. S. Forest Serv. NE Forest Exp. Sta., N. Y. State Museum and Science Service, and N. Y. State Conservation Dep. Unpublished report, 19 pp., 1961.

[2] Connola, D. P., F. B. Lewis, and J. L. McDonough. EXPERIMENTAL FIELD TECHNIQUES USED TO EVALUATE GYPSY MOTH CONTROL IN NEW YORK. (In press.)

[3] Regular trademark Fisons, Ltd., distributed by Stauffer Chemical Co. Mention of a particular commercial product should not be construed as an endorsement by the U. S. Department of Agriculture or the Forest Service or the New York State Museum and Science Service.

[4] Lewis, F. B., D. P. Connola, and J. L. McDonough. AERIAL APPLICATION OF A BACILLUS THURINGIENSIS SPORE-CRYSTAL CONCENTRATE IN FUEL OIL AND WATER FORMULATIONS FOR GYPSY MOTH CONTROL—NEW YORK STATE, 1962. U. S. Forest Serv. NE Forest Exp. Sta. Unpublished report, 54 pp., 1962.

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The Nature of Bt

Before discussing these field and laboratory experiments with *Bt,* it is apropos to review briefly the available information about the nature and mode of action of the active agent in the materials used in the tests.

Bt belongs to the aerobic, spore-forming, gram-positive bacterial genus *Bacillus. Bt* and five other species and several varieties form a distinct group within the genus, based on classical biochemical tests and the formation of a parasporal body (crystal) at the time of sporulation (Heimpel 1962). A serological typing system has been reported (DeBarjac and Bonnefoi 1962). All of these crystal-producing organisms are pathogenic for insects, principally the Lepidoptera, and as far as is known do not cause disease reactions of any sort in higher animals. In the United States, only one crystalliferous bacillus, *Bt,* is produced in commercial quantities; this is the active agent in the preparations used in the experiments reported here.

The life cycle of *Bt,* which is characteristic of the crystalliferous spore-forming group, will be used as an illustration. The cycle of the bacillus is essentially divided into two main stages: (1) the actively multiplying stage (the vegetative cell) and (2) the resistant dormant stage (the spore). The vegetative cell is not heat-resistant and requires a moist environment that contains suitable nutrients for growth and multiplication. During the multiplication of the vegetative cell, metabolic byproducts are excreted. Many of these are toxic to insect larvae. In the case of *Bt,* one of the byproducts (Phospholipase C) is known to be toxic to insects (Heimpel 1955; Bonnefoi and Beguin 1959).

In the restricted environment of the insect gut, as well as in a tube of nutrient medium, the active vegetative growth of the bacillus slows and eventually ceases because of exhaustion of available nutrients and adverse changes in the immediate environment. When these nutrients are exhausted, the vegetative cell undergoes a process that will enable the organism to survive under unfavorable circumstances. This process involves a shortening and thickening of the vegetative rod, and concurrently an

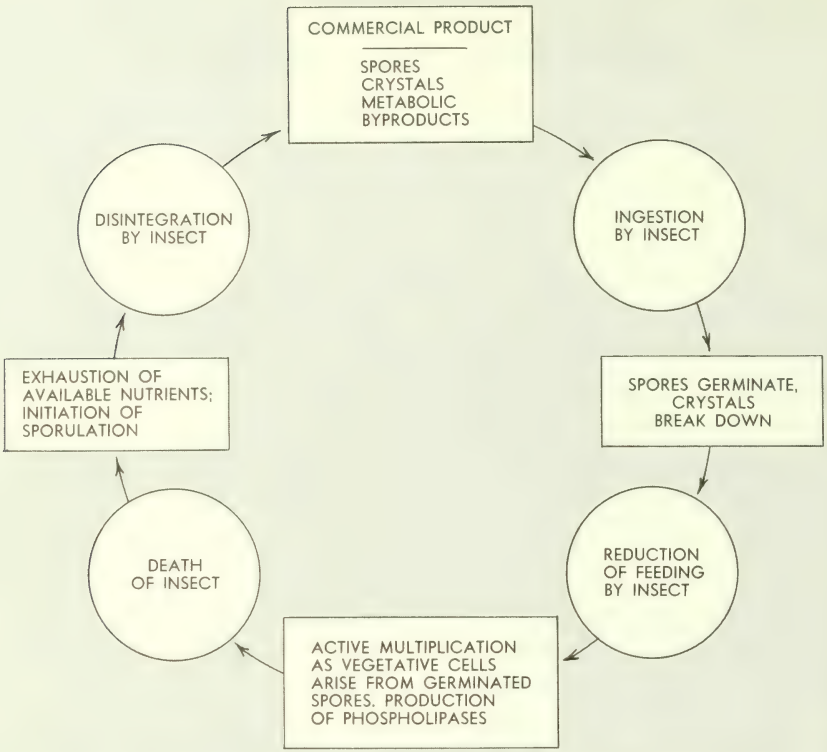

Figure 1.—A diagram of the life cycle of *Bt* as it would occur in a gypsy moth after ingestion of a commercial product applied for control purposes.

ovoid spore is produced in the rod along with, in the case of *Bt,* a diamond-shaped parasporal body or crystal.

Upon completion of this process, called sporulation, only the spore and crystal remain. Both the spore and crystal are heat-resistant and can remain in a dry environment for long periods of time without losing their viability or toxicity. In addition to the production of spore and crystal at the time of sporulation, complex soluble byproducts are also produced. One of these was first shown to be toxic to fly larvae (McConnell and Richards 1959).

Commercial *Bt* preparations are concentrates of the spores, crystals, and metabolic byproducts. The diagram (fig. 1) outlines

the life cycle of the organism as it would occur in a pest insect (gypsy moth) after ingestion of a commercial product applied for control purposes.

Several toxic principles are involved in killing the gypsy moth: the crystal, the so-called "fly factor," and phospholipases. Some information is available about the mode of action of the crystal (Angus 1956; Heimpel and Angus 1959; Bonnefoi and Beguin 1959), the fly factor (McConnell and Richards 1959), and Phospholipases (Heimpel 1955).

The diagram illustrates, in general, the known or suspected pathogenic effect of *Bt* and its life cycle in the gut of a gypsy moth larva. The larva ingests the spores, crystals, and metabolic byproducts contained in the commercial preparation. Within the insect's gut, the spores germinate and give rise to the vegetative cell (fig. 2). At the same time the crystal is dissolved or broken down under the influence of alkaline pH or enzymatic action that gives rise to a toxin. The toxin exerts a paralytic effect, causing in some insects a total and immediate paralysis and in

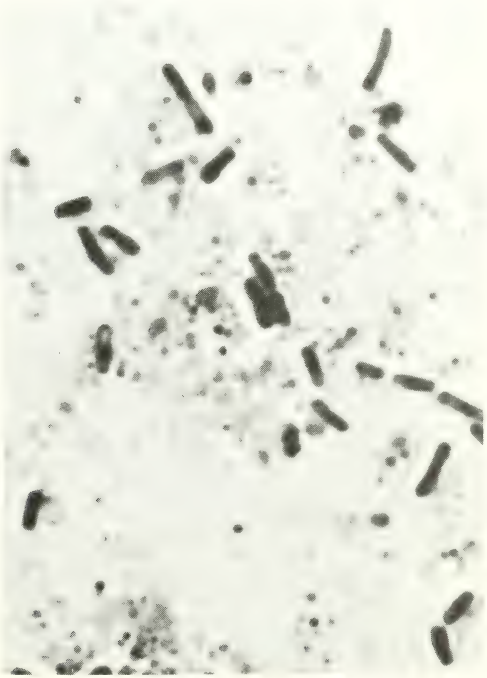

Figure 2.—Actively growing vegetative cells of *Bt*.

others only a gut paralysis in which the larva slowly desiccates (fig. 3). In the gypsy moth, total paralysis does not occur, and gut paralysis is only partial, which permits the affected larva to feed sporadically for several days. In addition to the direct paralytic effect of the crystal, toxic activity can occur because of the ingested metabolic byproducts contained in the commercial preparation. The mechanisms and significance of this activity in the gypsy moth are at present unknown.

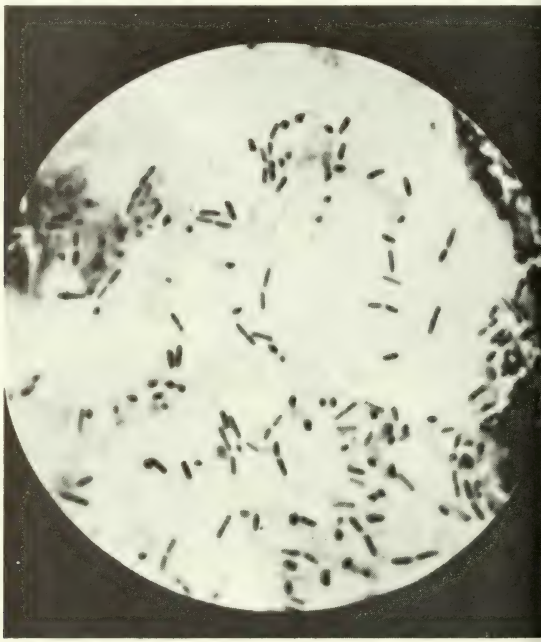

Figure 3.—Free spores and crystals in gut smear of *Bt*-killed gypsy moth larvae.

The events described occur rapidly after ingestion. However, in the gypsy moth, which is not immediately paralyzed by the ingested toxins, active multiplication of vegetative cells arising from ingested spores goes on until after the larva dies. Death of the gypsy-moth larva occurs 4 to 6 days after ingestion of the *Bt* material. The vegetative cells continue to multiply for 3 or more days in the cadaver until the nutrients are exhausted, whereupon the vegetative cells sporulate and give rise finally to only spores and crystals in the larval remains.

Materials and Methods

1961 Experiment

Field layout.—Seven woodlots were selected for spraying and three others were designated as checks by personnel from the New York State Conservation Department and the New York State Museum and Science Service. All selected woodlots had an estimated 300 to 2,000 gypsy-moth egg masses per acre, no known disease history, and indications of a rising population. An attempt was made to obtain predominantly oak woodlots. The plots were 25 to 200 acres in size and were located near Saratoga Springs, N. Y.

Treatments.—The *Bt* preparation[6] was applied by a Stearman biplane at three dosages (¼ pound, 1 pound, and 2 pounds in 2 gallons of water per acre) with tung oil as a sticker. The tung oil mix, supplied by Pesticide Chemical Research Division, Agricultural Research Service, contained an emulsifier that was not sufficient when the spray was first prepared at the airport. The addition of 1-percent experimental 9D-207 emulsifier (Rohm and Haas) corrected the situation and apparently gave an excellent suspension. One plot received the finished spray without the added emulsifier.

Each of the three treatments had two replicates. In addition, a seventh plot received ¼ pound *Bt* plus 48 x 10^9 polyhedra per acre of *Borrelinavirus reprimens* Holmes, which causes the nuclear polyhedral virus disease of the gypsy moth, commonly called gypsy-moth wilt disease.

Evaluation procedure.—Five 0.1-acre subplots were established in each of the 10 experimental plots. Four types of samples were taken in each of these subplots.

- Three sets of five sleeve cages, each containing 25 healthy larvae each were placed on foliated branches within reach of the ground in each subplot. One set was placed immediately after spraying, another 4 days after spraying, and the last 8

[6] Thuricide wettable powder with a spore count of 60 x 10^9 per gram; product of Bioferm Corp., Wasco, Calif.; distributed by Stauffer Chemical Co., New York.

Figure 4.—Sleeve cage used in the 1961 field test.

days after spraying. The sleeve cages were examined every other day for 16 days and then removed. Dead larvae were collected from the cages as found and mailed to the Forest Insect Laboratory at New Haven, Conn., or transported by car to the Bacteriology Department, University of Connecticut, Storrs, for examination as to cause of death (fig. 4).

- One cloth drop tray (3 x 3 feet) was placed in each subplot. Dead larvae in these trays were sent to New Haven or Storrs for examination. In addition, 10 living larvae from each subplot were collected 2, 4, and 8 days after spraying, sent to Storrs, and serially plated on trypticase soy agar (TSA) to determine the amount of *Bt* spores and cells present in the insect.

- Leaf samples were collected in each subplot approximately 2, 4, and 8 days after spraying. One lot was sent to the Bioferm Corporation for a viable spore count; a second lot was sent to the Insect Pathology Pioneering Research Laboratory, Agricultural Research Service, Beltsville, Md. for a similar count.

- Before- and after-treatment egg-mass counts were made in all plots. In one plot the counts were made in the 0.1-acre subplots. In all other plots, the egg-mass counts were made along string lines between the subplots.

Laboratory methods.—No laboratory tests preceded the 1961 field test. However, after the field test a series of experiments were conducted to determine the effectiveness of the tung oil sticker and the effects of the 9D-207 emulsifier on the activity of the experimental material. The same commercial preparation of *Bt* was used in these tests as in the field test. Three formulations were used: (1) *Bt* powder in water alone; (2) *Bt* in water with tung oil added; and (3) *Bt* in water with tung oil and 9D-207 emulsifier added. The tung oil and emulsifier were added at the same concentrations as used in the field.

1962 Experiment

Experimental areas.—Twenty-seven woodlots, averaging 73 acres, were used in the 1962 experiment. All woodlots were located in eastern New York and were predominantly oak. The initial insect populations in these plots were 150 to 2,000 egg masses per acre, except for one plot, which approximated 8,500. There was no known disease incidence in any of the experimental areas in 1961. Twenty-four plots were treated in three series of eight each, and three were used as checks (one in each series).

Treatments.—Based on the results of the 1961 experiment, three *Bt* concentrations again were chosen: 1, 2, and 4 pounds per acre. In addition, more plots were treated with the combination of the bacillus and the polyhedral virus. The dosages used were as follows:

- 4 pounds Thuricide[7] in 4 gallons of diluent per acre.
- 2 pounds Thuricide in 2 gallons of diluent per acre.
- 2 pounds Thuricide plus 50 x 10^9 polyhedra in 2 gallons of diluent per acre.
- 1 pound Thuricide plus 50 x 10^9 polyhedra in 2 gallons of diluent per acre.

The four dosages were applied in two diluents: (1) No. 2 fuel oil and (2) water with 6 ounces of Lovo 192 per gallon of

[7] Thuricide 65 B, product of Bioferm Corp., distributed by Stauffer Chemical Co., New York.

spray. The eight treatments were replicated three times, each replicate constituting a series. Each series was completed before the next was begun. The sprays were applied by two Stearman biplanes, one of which applied the oil sprays and the other the water sprays. The treatments were begun when oak leaf expansion was nearly complete, and the gypsy-moth larvae were in the second and third instars.

Evaluation procedure.—In 1962, certain modifications were made in previously used evaluation procedures. Seven methods were used, as follows:

1. Spray-deposit data obtained in 1961 had two major shortcomings: samples were taken from understory foliage and thus were not representative of the spray distribution; and considerable time elapsed between sampling and the analysis of deposit, which permitted both spore death and germination. In 1962, foliage was pole-pruned from the lower half of the crowns of treated oaks, and petri dishes containing TSA were placed below openings in the canopy at each of the five subplots in two of the three series. To eliminate the time lapse between sample collections and deposit analysis, a field laboratory[8] was established in Saratoga Springs, N. Y. This laboratory greatly facilitated the evaluation procedures.
2. Mortality data obtained from the sleeve cages in 1961 was inadequate because the cages were placed on understory foliage, which did not represent the spray deposit; and the cages collapsed during the rain. To compensate for these deficiencies, a rearing station was established after treatment in the central subplot of each experimental plot. Five 12 x 12 x 6-inch screened cages constructed of waterproof plywood were placed on a rack at the Station—one cage for each of the five subplots in the plot. Each cage was supplied with 25 healthy larvae and foliage pole-pruned from the corresponding subplot. Foliage was replaced every other day. Dead larvae were removed from the cages and taken to the field laboratory for microscopic diag-

[8] Facility provided by the N. Y. State Conservation Department at its Saratoga Spa laboratories.

Figure 5.—Rearing station and *Bt* mortality cages used in 1962 experiment.

nosis of cause of death. Approximately 3,500 larvae were examined (fig. 5).

3. Frass samples were collected in cheesecloth dropping cloths suspended in hammock fashion under oak trees in each subplot of certain plots. This frass was collected at intervals, dried, and weighed after debris and non-gypsy-moth frass had been removed. The frass was also segregated according to the third, fourth, and fifth to sixth instars, and the pellets were counted (fig. 6).

4. Ten-minute counts of living larvae were made by researchers as they walked slowly along the string-line that connected the five subplots. This method of counting was used only when the larvae were third instar or larger.

5. Defoliation estimates were made at the completion of the larval feeding period in each subplot. No defoliation readings were made before spraying.

6. Before- and after-spray egg-mass counts were made at the same places in the treated plots in the 1962 experiment in contrast

Figure 6.—One type of drop tray used in the field tests.

to before-spraying egg-mass counts taken in different locations from after-spraying egg-mass counts in the 1961 experiment. This was done to minimize the wide variation in population numbers that normally occurs in different parts of each woodlot and to provide a better basis for measuring control.

7. The water-based and oil-based formulations of the active material were pre-tested at Beltsville, Md., and New Haven, Conn., for physical characteristics and biological effectiveness of the proposed field dosages.

Laboratory procedures.—Because the 1961 field test indicated the need for concurrent laboratory tests, a field laboratory was set up to provide facilities for the laboratory phase of the 1962 experiment. This phase was primarily for the purpose of examining spray deposit and dead larvae from the cages for the cause of death.

Two methods were used to check spray deposit on experimental

plots: (1) leaf collections before spraying, immediately after spraying, and 8 days after spraying; and (2) exposure during spraying at each of the five sampling subplots of a 10-cm. petri dish containing TSA.

In the first method, oak leaves were collected by pole pruner in each subplot and placed in plastic bags. The bags were then returned to the field laboratory immediately after collection, and 4 grams of leaf material were weighed out and washed with agitation for 15 minutes in 200 ml. of phosphate-buffered distilled water. The washing produced what we considered to be a 2×10^2 dilution. Two other dilutions—2×10^3 and 2×10^4—were made from this original dilution. These dilutions were heat-shocked at 65°C. for 30 minutes and plated (0.5 ml. per plate) on TSA. Finally, the plates were incubated at 37°C. for 20 hours before the colonies were counted. The counts were recorded as spores per gram of leaf material.

In the second method, one petri dish was placed below an opening in each subplot and the lid was removed immediately before spraying began. At the conclusion of spraying, the lids were replaced and taped, and the petri dishes were returned to the field laboratory. The plates were incubated for 24 hours at 37°C.; then the colonies were counted. The colonies represented droplets and not individual spores.

All dead larvae found in the cages in the plots were returned to the field laboratory in sterile tin pill boxes. Here the larvae were macerated, smeared on microscope slides, stained with Buffalo black-Safranin O, and examined for the presence of spores, crystals, and vegetative cells of *Bt.*

Additional laboratory analyses were made of the viable spore concentration of the finished sprays applied to each plot. Aliquots of the finished spray were removed from the tank in the airplane and taken immediately to the field laboratory. Tenfold dilutions of an aliquot were made, plated out on TSA, incubated at 37°C. for 24 hours, after which the colonies were counted. The concentration of the viable spores determined in this manner in the finished spray was compared with the theoretical concentration calculated from the manufacturer's label count.

1963 Experiment

Experimental areas.—Eleven woodlots, primarily composed of oaks, were selected for the 1963 experiment. They were located in the Duanesburg-Schenectady area of New York State and ranged from 30 to 100 acres in size. One woodlot was composed of three segments, which were treated the same but assessed separately. The initial insect population in the plots ranged from 2,200 to 10,000 egg masses per acre. The higher initial populations were permitted in order to have a better comparison between treated and untreated areas, although the hazard of higher natural disease was greater than in the previous tests.

Treatments.—The treatments used in 1963 were based on the results of the 1962 experiment. No oil formulations were used, and the active ingredient, assessed by biological activity, was applied in water formulations only. The formulations used were: (1) 1 gallon of Thuricide 90T Flowable[9] in 1 gallon of water; (2) ½ gallon of 90T in 1½ gallons, and (3) ½ gallon of 90T plus 15 x 10^9 *B. reprimens* polyhedra in 1½ gallons. All applications were made at the rate of 2 gallons of finished spray per acre. There were three replications of each dosage. Each replicate was referred to as series I, II, and III; and each series was completed before the next was started. All treatments were applied when oak leaf expansion was complete and the larvae were second instar or larger. Application was made with a U. S. Department of Agriculture Piper Super Cub 135.

Evaluation procedures.—Experience with caged larvae in the 1961 and 1962 tests indicated that the data provided by this technique did not correlate satisfactorily with the final results of the experiments. Therefore the use of caged larvae was discontinued.

Additional modifications were made in the evaluation procedures used in the 1963 experiment as a result of experience during the 1962 test. The major changes were in the elimination of techniques that did not provide useful information and in the

[9] Product of Bioferm Corp., Wasco, Calif. distributed by Stauffer Chemical Corp., N. Y.

increased concentration on pre-test evaluation of the material. The field evaluation techniques used in 1963 were as follows:

- The use of cheesecloth dropping cloths for the collection of frass proved to be very useful in the 1962 experiment; therefore they were employed in the 1963 experiment. A dropping cloth was established in each subplot before spraying and was maintained until feeding activity of the larvae ceased. Collections were made two or three times a week and were handled in the same manner as in 1962. In 1963, dead larvae were picked up in the cheesecloth hammocks and from leaves in each subplot and were returned to the field laboratory for microscopic examination. These examinations provided sufficient information on the course and cause of mortality in the treated plots, and gave evidence of a change in biological activity of the *Bt* material (fig. 7).

- Ten-minute counts of living larvae proved to be useful in assessing the trend of the population after spraying in 1962. Larval counts were made in 1963 in the same manner as in 1962.

- Defoliation estimates were made in all subplots before spraying and at intervals until larval feeding ceased. In each subplot estimates were made of (1) oak defoliation only, and (2) defoliation of all tree species considered together.

- The number of egg masses per acre after spraying was specified as the primary criterion of control in 1963. However, to minimize the amount of labor and time used on the final egg-mass counts, a preliminary egg-mass count was made in all plots immediately after egg deposition. Plots that showed 50 egg masses per acre or less were examined in greater detail after leaf fall, and all plots that had more than 50 egg masses per acre were eliminated from further examination.

Laboratory procedure.—Experience in the 1962 test indicated that detailed before-spraying checks must be made of the biological activity of the active *Bt* ingredient, of the physical characteristics of the concentrate, and of the concentration of viable spores and crystals in the bulk concentrate. Further, during the actual

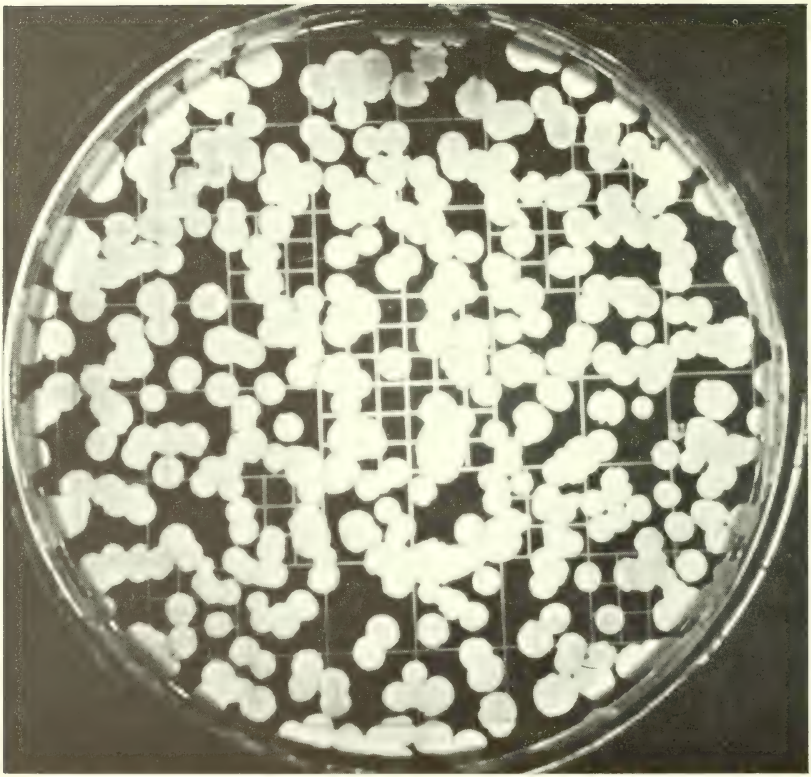

Figure 7.—*Bt* colony growth from spray droplets caught on agar-filled petri dish exposed during spraying.

spraying operations, checks must be made of the concentration of viable spores and crystals in the finished spray mixes. As a result, a large number of checks were made before and during the spray operation. All pre-testing of the 1963 material was done on production samples shipped in bulk as they would be for a control operation.

Prespray laboratory tests.—Biological-activity determinations were conducted with the proposed field dosages from the emulsifiable concentrate, and the new material was compared with the powder formulation used in 1962 for biological equivalence. The sticking qualities of the new material were tested under 10 inches of simulated rain. Since a fluorescent tracer was to be used for

spray deposit assessment, the biological compatibility of the tracer and the *Bt* concentrate was examined.

The physical characteristics of the new material, such as mixability and flowability, were tested at the Beltsville Forest Insect Laboratory. The aircraft to be used in applying the sprays were pre-checked for flowability of the sprays and were calibrated to deliver 2 gallons of spray per acre.

To assure that no settling had occurred in the drums of concentrate shipped to the airfield, aliquots were taken from the top, middle, and bottom third of each drum. These aliquots were diluted with 10-fold dilutions of phosphate-buffered distilled water. The dilutions were heat-shocked and plated on TSA as described previously. The viable spore concentration in each drum layer was obtained from dilution plates and compared with the labeled concentration. Crystal concentrations in each level of each drum were determined by Breed smears stained with Buffalo black.

Laboratory tests during spraying.—To guard against any loss of viable spores or crystals during the mixing and loading operations, a sample of the finished spray was taken from the spray tank of the aircraft. This aliquot was subjected to the microbiological procedures described previously for viable spore and crystal determinations. The actual concentrations of the finished sprays were compared to the theoretical concentrations based on the spore and crystal counts made of the drum concentrates used to formulate the finished sprays.

Results and Discussion

Field Operations

Field mixing and application.—In the 1961 test, all formulations were hand-mixed at the airport in 50-gallon drums. A circulating pump kept the finished spray in suspension. The material for each experimental plot was mixed just before application after a telephone call from field observers on the plots indicating that spraying conditions were suitable. The first plot sprayed did not receive the tung-oil sticker nor the added 9D-207 emulsifier because the emulsion was unstable in the aircraft. All other plots received the full amount of tung oil and additional 9D-207 emulsifier. During the application of the finished spray to the experimental plots, considerable trouble was encountered with clogging of the boom and nozzles on the aircraft due to settling of the *Bt* agglomerates and debris.

In summary, three major problems occurred (principally in mixing and application) in the 1961 test: (1) poor communication between the observation crews at the plots, the spray aircraft, and the airport due to lack of radios; (2) inadequate mixing and storage facilities at the airport; and (3) clogging of the spray in the plane's boom and nozzle system.

These problems were corrected in all but one important aspect during the larger field test in 1962. Radios were used in the 1962 experiment, which speeded up communications between the field plots, spray planes, and the airport. Mixing and loading facilities were improved so that the mechanical mixing, recirculation, and metering replaced the hand paddle and circulating pump used in 1961.

The physical characteristics of the oil-*Bt* concentrate and the water-Lovo 192-*Bt* concentrate still gave considerable difficulty in the field, contrary to data accumulated in pre-spray tests. The problem of keeping the *Bt* material in suspension in both the oil and water sprays was not overcome. Clogging of the aircrafts' booms and nozzles did not occur, but the *Bt* particulate material would not stay in suspension in the mixing tanks or the airplane tanks. This was particularly true of the oil suspension. As a

result, less than one-half of the specified amount of material in water-*Bt* suspensions and as little as one-thirtieth the desired concentration of the oil suspensions was transferred into the planes (table 1).

Table 1.—*Specified and estimated dosages applied to experimental Bt plots, 1962*

Specified dosage per acre	Estimated dosage of *Bt* per acre in—	
	Oil	Water[1]
Pounds	*Pounds*	*Pounds*
4	0.32	1.40
2	.16	.70
1	.08	.35

[1] Calculated from agar plate counts of viable spores in finished sprays.

The principal difficulty was discovered at the end of the first day's spraying. In cleaning the 660-gallon tank used to mix the oil-*Bt* suspension, a large amount of sediment was discovered at the bottom. A 50-gallon drum of the oil-*Bt* concentrate then was opened (the *Bt* concentrate that was diluted with oil was compounded with 4 pounds of *Bt* powder concentrate, ball-milled with 1 gallon of No. 2 fuel oil); and a 1-to-2-inch-thick layer of sediment was found hard packed on the bottom. It became apparent that the *Bt* powder had settled out of suspension during shipment. This sediment could not be re-suspended by rolling or tipping the drums.

The discovery of the sediment in the mixing tank and drum made it necessary to make additional checks on the delivered concentrates.

The operational problems encountered in 1961 and 1962 made any further aerial testing of *Bt* powder formulations of doubtful value until the announcement of a new liquid emulsifiable concentrate in late 1962.

Extensive pre-testing of production samples in bulk containers indicated that the physical characteristics of the new liquid formulation were excellent and would, in fact, eliminate the opera-

tional problems. These predictions were amply fulfilled during the field operations of the 1963 test. No difficulties were encountered in the mixing and application of this new emulsifiable concentrate. However, a new problem relating to the biological activity of the material arose. This is discussed in the section on Supplementary Laboratory Studies.

Control Effects

Primary criteria.—As indicated previously, the primary criteria used to judge the effectiveness of the experimental *Bt* materials were the percentage of egg-mass reduction and the number of residual egg masses per acre.

Table 2 shows the results of the 1961 experiment. In this test, two treatments (plots 3 and 7) gave significant egg-mass reductions. The only real difference between the treatment of plot 3 and all other plots was in the formulation of the spray applied to it. Plot 3 was sprayed before it was noticed that the emulsifier in the tung oil was not sufficient to produce a stable

Table 2.—*Results of Bt spraying experiment in New York State, 1961*

Plot No.	Dosage	Egg masses per acre before spraying	Egg masses per acre after spraying	Reduction
	Pounds	*Number*	*Number*	*Percent*
1	2	350	510	—
2	1	1,400	25,350	—
3	[1] 1/4	1,500	40	97.3
4	2	400	575	—
5	1	1,200	10,760	—
[2] 6	—	1,400	7,772	—
7	[3] 1/4	1,200	219	81.75
8	1/4	1,120	2,440	—
[2] 9	—	[4] 1,200	99	91.75
[2] 10	—	2,000	[5] 1,252	37.40

[1] Spray without emulsifier.
[2] Check plot.
[3] *Bt* plus virus.
[4] Heavy winter kill reduced this figure.
[5] Very heavy polyhedrosis occurred in this plot.

emulsion. Thus plot 3 received the *Bt* material essentially in water alone, with little or none of the tung oil. All other plots received a stable emulsion including the tung-oil sticker.

Later laboratory tests showed that the tung oil and the added emulsifier had an inhibitory effect on the biological activity of the *Bt* material. Thus plot 3, which received the *Bt* without the sticker and added emulsifier, showed the lethal activity of the *Bt* more fully. Plots 1 and 4, which received 2 pounds of *Bt* per acre, had little change in egg masses per acre because the full effect of the material was blunted by the additives, but sufficient control was obtained to keep the populations stable. On the other hand, plots 2 and 5, which received 1 pound of *Bt* per acre, had a large buildup of egg masses per acre because the deleterious effect of the additives nullified the action of the *Bt.* Although only plot 7 received the combination of *Bt* and the nuclear polyhedral-virus disease organism, the large reduction in egg masses gave hope that this combination treatment would be more effective than *Bt* alone.

Table 3 presents the composite data for the 1962 experiment. Only plot 11 showed an egg-mass survival count low enough to be considered satisfactory, and only plots 6 and 11 showed significantly large egg-mass reductions.

The average reduction in egg masses per acre in the three check plots was 1.1 percent; and only 11 of the treated plots showed an egg-mass reduction greater than this. As far as treatment is concerned, there was no consistency in these reductions except in the plots treated with 4 pounds of Thuricide in 4 gallons of water per acre. The six plots that showed greater reductions than the checks received oil formulations, and the five others received water formulations. Six of the 11 plots received the combination treatment of the *Bt* plus polyhedral virus, and five received only the *Bt.*

The results of the 1962 experiment in terms both of egg-mass reduction and residual egg masses per acre showed that the 4 pounds of active material in 4 gallons of water gave the best results. The second best treatment was 2 pounds of active ingredient in 2 gallons of No. 2 fuel oil. The third best treatment

Table 3.—*Results of Bt field tests in New York State, 1962*

Plot No.	Dosage, per acre[1]	Initial egg masses per acre	Final egg masses per acre	10-minute larval count	Average frass per day per hammock	Average pellets per day per hammock	Cage mortality due to *Bt*	Defoliation
	Pounds	*No.*	*No.*	*No.*	*Gm.*	*No.*	*Percent*	*Percent*
1	2 (oil)	424	156	2.0	0.03	28.9	5	8
2	2 + (water)	290	190	3.5	.12	106.6	3	5
3	Check	960	498	158.3	.08	74.3	0	15
4	2 (water)	650	570	32.5	.49	218.4	54	13
5	2 + (water)	1,850	720	6.2	.06	59.9	12	15
6	4 (water)	1,350	310	4.4	.05	39.5	52	7
7	4 (oil)	360	840	44.6	.64	644.4	10	26
8	1 + (oil)	570	240	12.0	.07	64.1	14	12
9	1 + (oil)	410	794	135.6	.24	151.5	6	28
10	2 + (oil)	190	140	22.5	.12	89.7	6	5
11	4 (water)	520	26	.6	.01	10.9	78	13
12	Check	1,130	1,512	31.4	.57	403.0	0	20
13	2 (water)	1,200	1,490	23.6	.45	334.1	84	25
14	1 + (water)	350	1,400	54.5	.60	265.1	11	13
15	1 + (water)	616	310	5.1	.05	40.3	56	5
16	2 + (oil)	1,044	808	15.2	.46	375.1	10	24
17	1 + (oil)	496	8,738	190.0	—	—	8	26
18	4 (water)	626	1,528	13.7	—	—	66	7
19	2 + (water)	968	4,184	247.00	.47	325.0	28	26
20	2 (water)	1,248	29,274	410.0	—	—	1	45
21	4 (oil)	1,648	26,352	393.0	—	—	36	47
22	2 + (water)	546	312	6.1	.08	49.0	37	5
23	1 + (water)	428	7,176	28.0	1.01	457.4	62	32
24	Check	320	284	2.4	—	—	0	14
25	2 + (oil)	269	90	.4	—	—	4	5
26	2 (oil)	228	632	14.2	.03	34.0	22	5
27	4 (oil)	8,500	5,624	93.1	1.86	1,295.0	24	40

Table 4.—*Results of Bt field test in New York State, 1963*

Plot No.	Dosage, per acre[1]	Initial egg masses per acre[2]	Postspray		Egg-mass Change per acre	10-minute larval count	Average frass per day per hammock	Final oak defoliation
			Preliminary egg masses per acre	Final egg masses per acre				
	Gallon	*No.*	*No.*	*No.*	*Percent*	*No.*	*Gm.*	*Percent*
1	½	3,622	48	174+	98.6	6.3	0.06	9.2
2	½+	1,787	744	—	58.4	10.8	.38	12.6
3	1	4,674	5,136	—	+109.9	26.4	.37	17.4
4	½+	5,082	792	—	84.4	20.1	.31	11.2
5	½+	4,269	15,554	—	+364.4	149.8	2.60	73.0
6	½	3,173	144	170+	95.5	12.0	.10	11.6
7A	1	6,605	3,000	—	54.6	46.9	.43	11.8
7B	1	8,082	1,704	—	78.9	20.8	.40	13.0
7C	1	3,469	752	—	78.3	59.3	.16	12.4
8	½	2,560	26	65+	98.9	2.0	.03	7.6
9	1	5,423	2,844	—	47.56	21.8	.49	17.2
10	[3]	4,703	504	796	83.1	6.9	.08	9.8
11	[3]	2,286	10,730	5,650	+247.0	—	—	50.0

[1] + indicates addition of polyhedra of *Borrelinativus reprimens* Holmes.
[2] Corrected for winter kill.
[3] Check plot.

was 2 pounds of active ingredient plus 50 billion polyhedra in 2 gallons of water. The egg-mass reductions in the latter two treatments were very close, but neither brought about a residual egg-mass count low enough for practical control.

The composite data of the 1963 Thuricide 90T test are shown in table 4. As was indicated in the section on Materials and Methods, a modification of the egg-mass sampling was made in 1963. Thus there are two columns in the table for egg-mass counts after treatment. Only three of the treated plots (plots 1, 6, and 8) showed, in the preliminary egg-mass tally, a residual egg-mass number below or near the arbitrary limit of 50. Therefore only these plots plus the check plots were examined in greater detail for the final egg-mass count. None of these plots showed 50 or less residual egg masses per acre in the final tally; so in these terms satisfactory control was not obtained. However, the reduction in egg-mass numbers in these plots was over 95 percent.

Although the specified degree of control was not achieved in this test, there was a consistent pattern in the result. The ½ gallon of 90T in 1½ gallons of water per acre was the best treatment in all series. The higher concentration (1 gallon 90T in 1 gallon water) gave significant reductions in egg masses, but consistently lower reductions than the lighter concentration gave. The probable reason for this was revealed in the laboratory tests.

Secondary criteria.—The secondary criteria used in these experiments were (1) to assess the effects of the treatments during the development of the larval stage of the insect and (2) to account, insofar as possible, for some mortality effects not attributable to the treatments.

One secondary criterion was larval mortality in sleeve cages. The use and limitations of the cages used in 1961 have been described. Regardless of the limitations, the sleeve cages showed that the residual effects of the *Bt* treatments lasted up to 8 days. This suggested that the principal mortality due to the active material—as well as the effectiveness—was limited to 1 week or less. Table 5 gives the pertinent data on cage mortality in the

Table 5.—*Percentage of larval kill in sleeve cages after Bt treatment, in New York, 1961*

Plot	Dosage	Mortality		
		Immediately after *Bt* treatment	4 days after *Bt* treatment	8 days after *Bt* treatment
	Pounds	*Percent*		
E-3	1/4	29	12	5
E-10	[1]	0	1	2
E-1	2	77	56	27
E-2	1	34	19	27
E-5	1	30	23	20
E-8	1/4	25	10	5
E-9	[1]	0	1	1
[2] E-4	2	18	22	17
[3] E-7	1/4+	[4]40 (63)	21 (43)	10 (20)
E-6	[1]	9	9	[5]13

[1] Check plot.
[2] Larvae mostly fourth instar, gusty winds, heavy rain 8 hours after application.
[3] Heavy rain 8 hours after application.
[4] The figures in parenthesis indicate mortality due to *Bt* and virus combined.
[5] E-6 may have been contaminated by spray from E-5. These plots were relatively close together and nozzle clogging over E-5 caused lengthy spraying in gusty winds.

1961 experiment. There was no apparent correlation between cage mortality and egg-mass reduction (table 2).

In the 1962 experiment, a modification of the cage-mortality technique was attempted (see Material and Methods section). The major portion of the manual labor involved was used in maintaining these cages. As can be seen from table 3, the mortality due to *Bt* in the cages was relatively low; and table 6 shows that there was no correlation of the data obtained by the caging technique and the egg-mass data. Therefore, this method of treatment evaluation appears to be inefficient in terms of manpower required and validity of the data obtained.

In the 1963 experiment no caged larvae were used. Dead larvae were picked up from drop cloths and foliage, and were microscopically examined for cause of death. Although this technique was not used as a criterion of treatment effectiveness, the examination of these larvae gave information on the cause of death. The operation of other mortality factors, such as virus or insect

parasites, could thus be accounted for. An important finding in the examination of these larvae was the reduced number of multiplying vegetative cells of *Bt* over those noted in previous experiments. In addition, many abnormal and "ghost" cells were observed. These observations gave rise to the hypothesis that the new formulation was, in some way, inhibiting feeding of the larvae or changing the normal physiology of the *Bt.*

The use of drop trays in the 1961 experiment proved to be inconclusive in evaluating the trend in effects of the treatment or the final result. However, one very striking effect was revealed

Table 6.—*Correlation data from different methods of evaluation, 1962*

Method	Correlation with egg-mass reduction[1]	Ranked values	Significance
Caged larvae	0.121	27	—
10-minute larval count	.803	27	**
Frass weight	.727	21	**
Frass number	.649	21	**
Spore deposit, on leaf	.241	27	—

[1] Calculated from equation $r = 1 - \frac{6d^2}{n(n^2 - 1)}$

**Statistically significant at the 1-percent level.

by the drop trays. This was the quick and apparently high degree of kill among spring and fall cankerworms (*Paleacrita vernata* (Peck) and *Alsophila pometaria* Harr., respectively) in all plots regardless of dosage. Cankerworms seemed to be nearly eliminated within 4 days after spray application. The effectiveness of *Bt* preparations against spring and fall canker worms in these studies agrees with that reported previously by Jacques (1961), Quinton and Doane (1962), and Thompson (1962).

More drop trays were used in the 1962 experiment. Gypsy-moth frass was collected and measured in terms of dry weight and number of pellets. Table 6 shows that both of these techniques

Table 7.—*Correlation of data from different methods of evaluation, 1963*

Method	Correlation with residual egg masses per acre	Correlation with percentage egg-mass reduction
Percentage egg-mass reduction	0.931**	1.000
Residual egg mass/acre	1.000	.931**
10-minute larval count	.868**	.833**
Prespray frass (wt.)	.826**	.931**
Postspray frass (wt.)	.881**	.881**
Final defoliation	.853**	.917**
Deposit (average colonies/plate)	[1]+.310, [2]—.330	[1]+.154, [2]—.153
Deposit (total viable spores/plate)	[1]—.264, [2]+.189	[1]—.125, [2]+.126
Deposit (average viable spores/drop)	[1]—.399, [2]+.400	[1]—.258, [2]+.259

[1] Ranked highest deposit to lowest deposit.
[2] Ranked lowest deposit to highest deposit.

correlated strongly with the egg-mass data and also gave information on the trend of mortality.

Drop trays were used in the 1963 experiment, and again the data obtained from them correlated highly with the egg-mass data.

Another secondary criterion of evaluation, not used in 1961, was the 10-minute larval count. Although the behavior of gypsy-moth larvae is greatly influenced by their density, stand conditions, and physical factors of the environment, the larval-count data correlated highly with the primary criteria of evaluation (tables 6 and 7). The details of this technique are described elsewhere (see footnote 2).

The apparent foliage protection afforded the treated plots in 1961 suggested the use of defoliation readings in future tests. Thus defoliation estimates were made in all 1962 plots after treatment. Because these readings reflected feeding by all defoliators before spraying, their value was somewhat questionable; and in 1963, defoliation estimates were made before spraying as well as at the conclusion of the gypsy-moth larval feeding. Table 7 shows that the correlation between final defoliation and the primary criteria of evaluation was strong.

In the evaluation of any field test of an insecticidal material, particularly of an experimental nature, the spray distribution and deposit must be measured. In all three experiments, several spray-coverage and deposit techniques were used. These methods proved useful only in evaluating spray coverage; they did not give useful information on actual spray deposit. Data in tables 6 and 7 show that there was no correlation between spray deposit and the final result of the experiments (fig. 8).

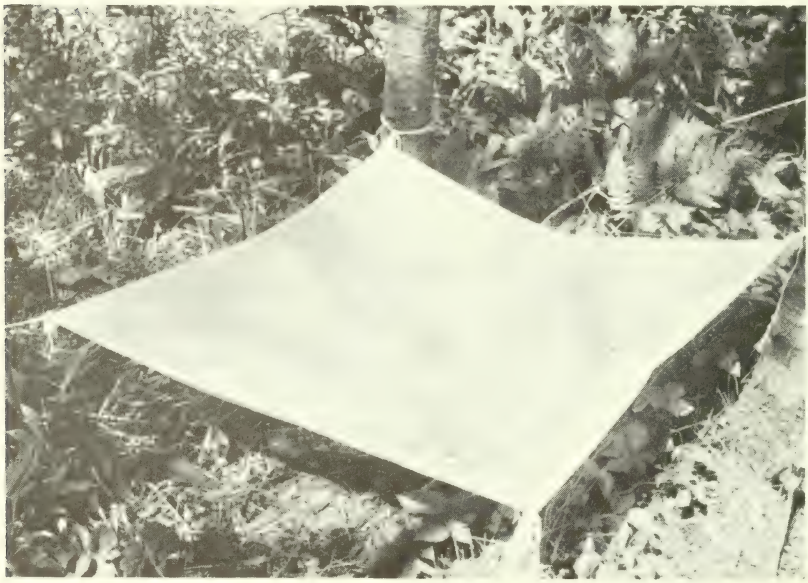

Figure 8.—A second type of drop tray used in field tests.

Supplementary Laboratory Studies

In the course of the three field tests described here, a number of supplementary studies were conducted at the field laboratory in Saratoga Springs, N. Y. and at the Forest Insect Laboratory in New Haven, Conn. The information gained in these studies was important in interpreting the results of the field tests.

In view of the work of Angus (1956) on the effect of gut pH on the activity of the crystal, and the work of Kushner and Harvey (1962) on the antibiotic effect of foliage, several experiments were conducted to gain information on these points.

Heimpel and Angus (1959) classified the action of crystalliferous bacilli on insects according to the speed and type of paralysis that occurs. It was of some importance to determine the general category of the gypsy moth. Tests were conducted on the feeding behavior of these larvae when challenged with *Bt.*

Moreover, additional tests were conducted on the effects of the components of the liquid concentrate on the germination of the *Bt* spore and the metabolism of the resulting vegetative cell. Other tests were conducted on the effect of the components on the feeding activity of the gypsy-moth larvae and any toxic effects that they may possess.

Methods and Results

Gut pH determinations.—Determinations of midgut pH were made on a Photovolt Model 110 pH Meter equipped with a Beckman single-drop electrode. Midguts of fed and unfed fourth, fifth, and sixth instar gypsy-moth larvae were surgically removed; the contents were then placed in the cup of the electrode; and pH readings were made immediately. All test larvae were reared on oak foliage, and at least 25 specimens were tested for each average reading.

Gut pH measurements of the alimentary tract of gypsy-moth larvae indicated that the alkalinity of the gut is low; thus this species should not be as sensitive to *Bt* as insects that have a higher gut pH. However, microscopic examination of guts of

Table 8.—*pH measurements of the alimentary tract and hemolymph of gypsy moth larvae*

Instar	Activity	Crop	Foregut	Midgut	Hindgut	Hemolymp
IV	Feeding	6.94	7.25	7.41	7.10	6.45
IV	Resting	6.71	7.54	8.63	6.35	6.18
V	Feeding	—	7.86	8.22	6.32	6.24
V	Resting	6.75	7.87	7.61	6.67	6.33
VI	Feeding	6.81	8.05	8.69	7.05	6.31
VI	Resting	7.21	7.72	8.50	6.58	6.40
Mean	—	6.96	7.72	8.30	6.67	6.32

gypsy-moth larvae that had ingested *Bt* showed that the crystals had dissolved. Therefore, although the midgut pH is low, it is either sufficiently high to dissolve the crystal, or proteolytic enzyme action is also involved. Table 8 gives the average pH values for the major regions of the gut and of the hemolymph.

Antibiotic effect of foliage.—Water extracts were made of the foliage of all host plants found in the experimental plots. *Bt*-seeded agar plates were challenged with these extracts to determine if antibiosis occurred.

None of the water extracts of foliage that the gypsy moth larvae were feeding on showed any inhibitory effect against *Bt*. The extracts tested were white oak, red oak, black oak, chestnut oak, hickory, white and yellow birch, American beech, and witch-hazel.

Gypsy moth larval gut presses.—Tests were made to determine if antibiotic modification occurred during ingestion and digestion by the larvae or if any antibiotic principle existed in the gut of the larvae. Gut presses of larvae feeding on host material found in the experimental plots were made. The larval guts were removed surgically, and slit longitudinally; and the contents of the dorsal and ventral halves of the gut were absorbed on clean filter paper strips. *Bt*-seeded agar plates were challenged with these filter paper strips to determine the presence of any antibiotic element.

Gut presses prepared from larvae feeding on the above-men-

tioned trees did not exhibit any inhibition against *Bt.* Thus the gut of the gypsy-moth larvae does not contain any antibacterial activity, nor does it modify the activity of ingested leaf material.

Feeding activity of gypsy-moth larvae.—Two lots of 25 larvae each were challenged with a strong dose of wettable *Bt* powder. The larvae were kept under constant observation for 8 days to determine the amount of feeding and general activity of the larvae. Twenty-five larvae were fed untreated foliage to provide a comparison.

Table 9 presents in synoptic form the results of the test in which gypsy-moth larvae were challenged with *Bt.* These observations indicate that the ingestion of *Bt* strongly inhibits the feeding activity of the third instar gypsy-moth larvae. No repellent effect was noted. The 25 check larvae completed development to pupae and emerged as healthy moths.

Table 9.—*Feeding behavior of Instar III gypsy moth larvae fed a strong dosage of Bt*

No. days from start of test	Feeding behavior
1	Check larvae feeding actively; oak seedling nearly defoliated. Larvae on treated foliage feeding very slowly, seedling only slightly defoliated.
3	Check larvae given new oak seedling. Treated larvae appear normal, but feeding markedly reduced.
4	Check larvae feeding heavily, growing normally. Treated larvae ceased feeding. One dead larva (polyhedrosis).
5	Check larvae feeding heavily, seedling changed. Eight treated larvae dead; six appear normal but not feeding. Original treated seedlings only lightly defoliated, and still edible.
7	Check larvae feeding normally; seedling changed. Three more treated larvae dead; remaining three alive; very sporadic feeding.
8	Check larvae still feeding normally, seedling changed. Last three treated larvae dead.

Sporulation of the bacillus in Bt-killed larvae.—To determine if sporulation and/or crystal formation occurred in the remains of *Bt*-killed gypsy-moth larvae, a time series of dead larvae were placed on clean microscope slides. Aliquots of these larvae were examined daily to determine if sporulation and crystal formation had occurred.

The cadavers of the larvae killed in the above test were examined at intervals for spore and crystal production. As indicated in table 10, the bacillus started sporulation between the second and third day after death of the insect, and all cells completed sporulation by the sixth day. Crystal formation was not inhibited in any way (fig. 3).

Table 10.—*Evidence of sporulation and crystal formation of Bt in dead gypsy moth larvae*

Days from death	Vegetative cells	Spores	Crystals
0	Present	Not present	Not present
1	Present	Not present	Not present
3	Sporulating	Present	Present
4	Sporulating	Present	Present
5	Sporulating	Present	Present
6	Absent	Many present, free	Many present

Gross fractionation of emulsifiable Bt concentrate.—The emulsifiable concentrate used in the 1963 field experiment was fractionated by centrifuging into the following components: (1) oil layer, (2) spore-crystal layer, (3) washed spores and crystals, and (4) spore-crystal washings. In addition to the four fractions, two dilutions of the whole concentrate and a laboratory preparation of *Bt* isolated from the concentrate were fed to individual fourth to fifth instar gypsy-moth larvae; 0.1 ml. of each of the test materials was placed on oak-leaf sections and presented to each larva, after which daily observations were made on the feeding activity of the larva. All dead larvae were examined for cause of death.

The results of feeding fourth and fifth instar gypsy-moth larvae gross fractions of the 90T concentrate used in the 1963 field test are presented in table 11. As the commercial concentrate containing stabilizers was diluted, or the spore and crystal fraction was washed, the larvae tended to feed more. The laboratory preparation that contained no additives inhibited feeding least.

Table 11.—*Percentage of gypsy moth larvae feeding on fractions of 90T Flowable and a laboratory preparation of the same strain of Bt*

Test fraction	Larvae feeding
	Percent
Commercial concentrate	11
Spore and crystal washings	30
Commercial concentrate (Dilute 1:1 with water)	40
Washed spores and crystals	48
Commercial concentrate (Dilute 1:4 with water)	55
Laboratory preparation of spores and crystals	75

Effect of emulsifiable Bt concentrate on Bt metabolism.— Through the courtesy of the Bioferm Corporation, the nature and amount of the stabilizing ingredients used in the 90T emulsifiable concentrate were made available for testing. The effects of the five ingredients on spore viability and vegetative-cell metabolism were tested individually and in all possible combinations. The various ingredients and combinations were placed in test tubes and seeded with 5×10^6 viable *Bt* spores. These tube cultures were maintained at room temperature for 55 days; then 0.1 ml. aliquots were removed from each tube, appropriately diluted, heat-shocked at 60°C. for 30 minutes, and plated on TSA by the drop-plate technique. Breed smears were prepared from the appropriate dilution for total spore and crystal determinations. Spore and crystal counts were made at the following time intervals (in days): 0, 1, 2, 3, 4, 6, 8, 10, 13, 15, 17, 20, 24, 27, 34, 41, 49, and 55.

Physiological studies were made of the vegetative cells that arose from the spores in contact with the ingredients. The following tests were conducted on days 0, 6, 13, 20, 27, 34, 41, 49, and 55: motility, colony form, gram stain, catalase production, gelatin proteolysis, litmus milk reaction, fermentation of glucose and lactose.

Table 12 summarizes the essential findings of these tests. Only changes in viable spore count, catalase production, proteolysis, and carbohydrate utilization are listed. In order to interpret the table, the normal reactions of *Bt* are: (1) no change in the number of viable spores should occur; (2) the vegetative cell should produce significant quantities of catalase; (3) proteolysis of gelatin should occur, and glucose and lactose should be utilized with the production of acid or alkali, respectively.

Table 12.—*Results of tests with components of 90T Flowable on Bt spore viability and vegetative cell metabolism*

Ingredients	Reactions that showed significant changes				
	Viable spore count	Catalase production	Gelatin proteolysis	Glucose utilization	Lactose utilization
NaCl	Slight drop	Positive	Positive	Acid	Alkaline
Triton, xylene, diesel oil	No germination after 27 days	Negative after 27 days	Negative after 27 days	No reaction after 13 days	No reaction after 13 days
Triton, diesel oil	No germination after 27 days	Negative after 27 days	Negative after 27 days	No reaction after 13 days	No reaction after 13 days
Triton	No change	Positive	Positive	Acid	Alkaline
Propionic acid	Slight drop	Positive	Positive	Acid	Alkaline
Water	No change	Positive	Positive	Acid	Alkaline

NaCl, Triton, xylene	No change	Positive	Reduced	Acid	Alkaline
NaCl, Triton, diesel oil	No germination after 27 days	Negative after 41 days	Negative after 41 days	Negative after 20 days	Negative after 13 days
NaCl, Triton	No change	Positive	Positive	Acid	Alkaline
NaCl, propionic acid	1-log drop	Positive	Positive	Acid	Alkaline
Triton, propionic acid	No change	Positive	Positive	No reaction after 20 days	No reaction after 20 days
NaCl, Triton, propionic acid	2-log drop	Positive	No reaction after 27 days	No reaction after 20 days	Alkaline
NaCl, Triton, xylene, diesel oil	No germination after 32 days	No reaction after 41 days	Positive	No reaction after 34 days	No reaction after 34 days
NaCl, Triton, xylene, propionic acid	1-log drop	Positive	Positive	Acid	Alkaline
NaCl, Triton, diesel oil, propionic acid	No germination after 23 days	No reaction after 20 days	Positive	No reaction after 20 days	No reaction after 20 days
Triton, xylene, propionic acid	No change	Positive	Positive	Acid	Alkaline
Triton, diesel oil, propionic acid	No germination after 25 days	No reaction after 41 days	No reaction after 41 days	No reaction after 20 days	No reaction after 20 days
NaCl, Triton, xylene, diesel oil, propionic acid	No germination after 23 days	No reaction after 20 days	Positive	No reaction after 20 days	No reaction after 20 days
Commercial 90T	No change	Positive	Positive	Acid	Alkaline

Conclusions

The conclusions that can be derived from the results of the 3 years' tests with *Bt* for control of the gypsy moth can be divided into general and specific categories as follows:

General Conclusions

- *Bt* appears to be practical as a biotic control agent for the gypsy moth. The three field tests exhibited progressively greater reductions of the insect population, and the 1963 test showed consistent results with the most effective dosage. Acceptable reductions were achieved in the 1963 test, and the residual population numbers were very nearly acceptable for practical control.
- The absolute necessity for thorough pre-testing (of both physical and biological properties) of any commercial *Bt* preparation against the target insect is amply demonstrated by the experiences in the three field tests.
- Thorough checking of the concentrations of spores and crystals in commercial concentrates and in the finished sprays must be done; also checks on the mixability and flowability of the finished sprays must be continued until reasonably uniform products are available from the manufacturer.
- Systematic field checks must be made on the target insect population after spray application to distinguish between *Bt* effects and the effects of natural mortality factors.
- It must be realized that the lethal effect of *Bt* applications—particularly against relatively insensitive species such as the gypsy moth—may not be immediate, and that the full effect of the treatment may take a week or more to be noticed.
- Foliage protection due to reduced larval feeding may be accomplished with or without a significant reduction in the larval population.
- Field evaluation techniques had to be developed to properly assess the effect of *Bt* against the gypsy moth. This probably will be true for other insect species.

Specific Conclusions

- It can be concluded from the 1961 and 1962 tests that the data obtained from caging larvae are not valid for estimating the true effects of a *Bt* treatment. However, such data may provide ancillary information about the relative rate of mortality.
- The fluorescent dye-tracer technique is the easiest and quickest technique for discerning spray-distribution patterns, including the detection of drift; whereas the petri-dish technique appears to be the best one for estimating spray deposit quantitatively (fig. 9).
- There is no apparent enhancement of the effect of *Bt* against the gypsy moth when the nuclear polyhedral virus is included in the spray in relatively small amounts.
- Because of the relatively short life of *Bt* sprays in the field, it is necessary to treat all of the infested area that contains sig-

Figure 9.—Set-up for obtaining *Bt* deposit (A = agar-filled petri dish, W = sterile water-filled petri dish).

nificant numbers of the insect to prevent re-invasion by larvae from contiguous untreated areas.

- It is necessary to apply *Bt* sprays when host foliage is nearly fully expanded and before significant defoliation occurs in order to achieve full deposit and maximum effectiveness of the material.

- Care must be taken in field evaluations of *Bt* materials when unexpected results occur. The active ingredients must be evaluated and the additives must be assessed for their possible role in producing unexpected results.

■

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The market for FIREPLACE WOOD in an urban area of Connecticut

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The market for FIREPLACE WOOD in an urban area of Connecticut

The Most Important Timber Product

FUELWOOD is Connecticut's most important timber product. Nearly two-thirds of the State's total roundwood output is fuelwood. In 1962 some 181,000 cords of fuelwood were produced from the State's forest lands. This compares with the sawlog harvest of 30 million board feet (approximately 60,000 cords) and a pulpwood cut of 26,000 cords (U. S. Forest Service 1965). And this is not all: besides the 181,000 cords produced as fuelwood, the equivalent of 90,000 cords of residues from wood-processing plants also enters the Connecticut fuelwood market.

Before World War II, fuelwood was used extensively as an industrial fuel and for domestic heating and cooking purposes. Since the war, coal, oil, electricity, and natural and manufactured

gases have replaced nearly all of the wood used as a basic fuel in home and industry. A few rural homes are still heated by fuelwood, but they are becoming increasingly rare (U. S. Bureau of Census, 1960).[1] The use of wood as an industrial fuel is limited mainly to the forest-products industries.

Despite the declining importance of wood as a basic fuel, the production of fuelwood in Connecticut has remained nearly constant over the past decade. The declining use of fuelwood in its more traditional markets has been offset by an increase in the consumption of fireplace wood. This has been brought about primarily by an ever-increasing number of fireplaces in new homes.

Because fireplace wood has become the most important timber product of Connecticut's forests, a study was made to obtain basic information about this aspect of the State's forest economy. Emphasis was placed on sources of supply and marketing practices.

The area selected for study was the New Haven metropolitan area and the surrounding suburban communities, a total area of about 20 square miles. This area has undergone rapid growth in the construction of single-family dwellings, most of which have fireplaces.

Data were obtained from an informal market survey of individuals and firms who handle fuelwood on a commercial basis in the study area. The survey was conducted in the summer of 1964.

In surveying the market, an attempt was made to contact all fuelwood sellers who sold more than 25 cords of fuelwood during the 1963-64 fall and winter fireplace season. Individuals and firms who sell smaller amounts were sampled only to the extent necessary to obtain a reliable indication of the nature of their operations.

Twenty-four firms were surveyed. They account for about one-half of the fuelwood sellers in the area, and handle an estimated 70 percent of the firewood sold to consumers in the New Haven area.

[1] An indication of the declining importance of fuelwood in rural communities is the volume of fuelwood cut by farmers. In 1950 Connecticut farmers harvested 57,000 cords of fuelwood from their woodlots; in 1954 they harvested 43,000 cords, and in 1959 they harvested 19,000 cords.

The Primary Demand

Consumer demand for firewood in a modern city is bound up with the history of this ancient product. An open fire has been a sacred object, a festive symbol, and the focal point of family and community life. Until recently in human history the main utility of an open fire has been heat. In today's centrally heated homes, heat can be obtained more conveniently and cheaply from other fuels. Yet people want and will pay for hearth fires. The fireplace and firewood are a luxury or entertainment item in today's market.

The urge to own a fireplace apparently is quite strong. The traditional association of hearth and home still affects a majority

Figure 1.—Today's fireplaces require relatively small sticks of wood. In Connecticut the usual fireplace log is 20 inches long and not greater than 6 inches in diameter.

of prospective house-buyers, according to New Haven real estate dealers. It costs from $500 to $1,500 to add a fireplace to a house, and the property tax assessment rises accordingly. One realtor estimated that in the area 80 percent of the new homes that cost over $23,000 have at least one fireplace.[2]

In 1964 an estimated 3,000 standard cords of fuelwood were consumed in the New Haven area by individual homeowners who burn wood in home fireplaces.

In this area, fireplace wood is air-dried hardwood, approximately 20 inches long and split at least once if over 6 inches in diameter (fig. 1). Oak, maple, and yellow-poplar are the most common species. Applewood and hickory are occasionally marketed separately because of their unique burning properties, but the volumes involved are not large.

Nearly 80 percent of the fireplace wood marketed in the New Haven area is sold in 1- or ½-cord units. Twenty percent is marketed in small units such as a "thrown pickup-load", a "trunkload", or a 15-to-20-stick "bundle". For cord and half-cord sales, the cubic volume of the cord corresponds to the standards defined by the Connecticut Bureau of Consumer Protection. For the usual 20-inch stick, the standard cord is defined as 104 cubic feet of "compactly piled wood". By law, the Bureau's definition of a standard fireplace cord is supposed to be used in all fuelwood sales, even for the smallest fraction of a cord. In practice, sales of trunkload, bundle, and occasionally pickup-load lots are completed without reference to the fractional cord volumes involved.

The average fireplace owner uses his fireplace from mid-September to mid-March, consuming about 1 standard cord of fuelwood. The heaviest use occurs on weekends and between Thanksgiving and New Year's Day.

About this average is a wide range. At one end of the scale are those who burn a few sticks of wood during exceptionally cold weather or on special occasions and holidays. Their total

[2] According to a recent survey of building firms, nearly all new homes in the Northeast priced over $18,000 have fireplaces (House and Home, 1964). In 1960 the average value of single family-owned homes in Connecticut was $16,000. Most new homes were priced significantly above this value (U. S. Bureau Census 1960).

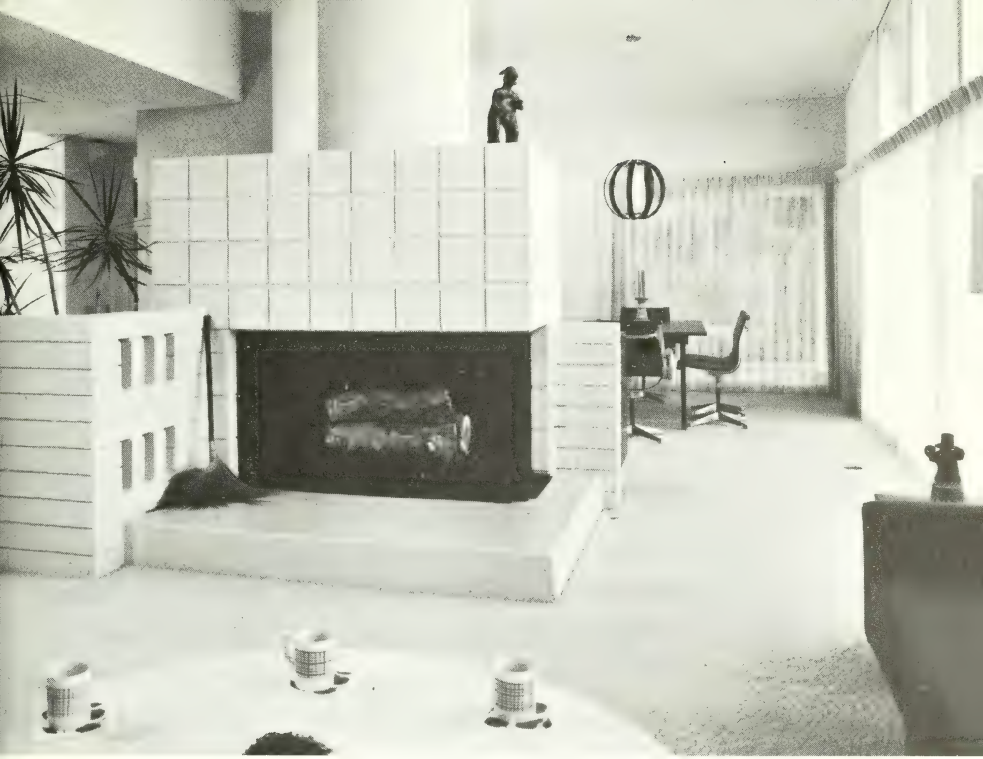

Figure 2.—In today's centrally heated houses a fireplace is a luxury that is often used primarily as an item of decor.

annual consumption is less than one-fourth of a standard cord. Among this group are those who derive most of their pleasure from using their fireplace as an item of decor rather than as a hearth (fig. 2). At the other end of the range is the consumer who uses his fireplace extensively. He consumes 2 or more cords of wood per year.

The size of individual firewood purchases is determined primarily by volume of total seasonal consumption and the availability of storage space. The homeowner who uses his fireplace only on special occasions normally purchases wood in small units. Typically, a bundle or trunkload of wood is purchased for each such special occasion. Consumers who use their fireplaces more frequently purchase in larger units. Those who have the room to store a full cord (8 feet x 4 feet x 40 inches) normally pur-

chase a cord at a time. Those who have more limited facilities purchase in ½-cord units. Nearly 80 percent of consumer purchases are made in cord or half-cord units.

There are few substitutes for commercially produced fireplace wood in the New Haven area. Few consumers cut their own fireplace wood. Many do not have a source of wood. Those that do usually find it financially unprofitable to use a power saw,[3] or physically inconvenient to use hand tools. Occasionally consumers are able to obtain fuelwood from land-clearing operations, but this source is usually limited to the landowner who is clearing a residential lot.

Sawmill residues provide a limited substitute, but are usually considered inferior to round or split wood. Though fireplace logs fabricated from sawdust and wood chips are common in some sections of the country, they have not been successfully marketed in the New Haven area.

Suppliers of Fireplace Wood

About 50 individuals and firms handle fireplace wood on a commercial basis in the New Haven area. Nearly 90 percent of these firms are retailers; their primary sales outlet is the final consumer. The remaining firms are wholesalers; the majority of their sales are made to retailers.

Without exception, both retailers and wholesalers rely on some other trade or occupation for a livelihood. They handle fireplace wood on a part-time basis and as a supplemental source of income.

Three-fourths of the suppliers are primarily engaged in occupations having an easily seen association with fuelwood: gardening and landscaping, land-clearing, commercial tree service, operation of nurseries and of garden shops. The remaining firms are engaged in primary occupations not normally associated with trees or fuelwood. Their relationship with fuelwood is generated

[3] A small power saw retails for about $200. At $3 per hour or $20 per day, renting a saw is expensive.

from their secondary occupations. Typical of this class of supplier is the moonlighting factory worker who removes trees from potential or existing house lots for a fee.

Retailers

Two classes of retailers operate in the New Haven area: producer-retailers and merchant-retailers. Producer-retailers engage in some phase of the manufacture of fireplace wood. Merchant-retailers purchase fully seasoned merchantable fireplace wood from wholesalers (or producer-retailers who also function as wholesalers) and sell to consumers without further processing of the same wood. A few producer-retailers also purchase wood from wholesalers, but the wood so obtained is not a salable product. It requires further processing, normally bucking and splitting.

In terms of consumer sales, producer-retailers are the most important. Ninety percent of the fuelwood purchased by consumers is obtained from retailers who undertake some phase of the fuelwood manufacturing process. Merchant-retailers handle the remaining 10 percent.

Producer-retailers.—Eighteen producer-retailers were surveyed. All of them undertake the entire fuelwood manufacturing and marketing process for at least some of the wood they handle. The retailer fells the trees from which fireplace wood is eventually derived, cuts felled trees into bolts, cuts the bolts into fireplace lengths, splits the larger bolts, and air-dries the manufactured product for 9 months to a year.

A few of the larger producer-retailers also purchase hardwood bolts from firewood wholesalers. With few exceptions, however, the amount of wholesaler-supplied wood is small. The exception is the largest fireplace wood seller in the New Haven area. The majority of this firm's raw material is purchased from a wholesaler in the form of green 5-foot bolts.

Producer-retailers undertake to manufacture the fireplace wood for a variety of reasons. A few of the larger retailers do so primarily because they feel that it is more profitable to undertake the manufacturing process themselves than to purchase a manufactured product from an intermediate market agent. Less than

10 percent of the New Haven retailers fall in this class, but they account for nearly 60 percent of the wood retailed in the area. This type of retailer normally markets 50 or more cords per year. Fifty percent of his wood supply comes from tree-removal operations undertaken in the course of his normal activities. The remaining half is obtained from wholesalers in the form of green 5-foot bolts, or occasionally as stumpage.

More common is the retailer who manufactures firewood for other reasons. Normally the source of raw material for this second class of retailer is trees that have been cut in small land-clearing or tree-removal operations.

For the latter group, the attraction of the retail firewood market is not based on the profit to be derived from the margin between conversion costs and retail prices. Nor is it based on the availability of a free wood supply. These firms are active in the firewood market primarily because they are periodically underemployed in their primary occupation. Firewood manufacture, consisting primarily of bucking and splitting of bolts removed from the site of tree felling, provides productive work during slack periods.

Merchant-retailers.—The three merchant-retailers sampled account for nearly all of the wood handled by this type of marketing agent in the New Haven area. The primary occupation of the retailers sampled lends itself to firewood retailing. Two operate nurseries and garden-supply stores; the third runs a hardware store.

Table 1.—Size class of sampled fuelwood retailers, 1963-64

Size class (cords sold)	Number of retailers
25 or less	10
26 - 50	4
51 - 100	2
More than 100	4
Volume not reported	1
Total	21

These firms retail firewood primarily because they operate the type of establishment at which consumers expect to be able to purchase wood. The incentive for handling wood is simply the profit to be derived from the retail operation.

Procurement and motivation aside, the only difference of consequence between these firms and their producer-retailer counterparts is size of operations. The average merchant-retailer sells 75 cords of fireplace wood per season. The average for producer-retailers is 25 cords.

Sales.—Retailer operations range in size of sales from less than 5 cords per season to more than 500 cords (table 1). A relatively small number of firms account for the majority of sales. Four of the 21 retailers sampled handled more than 100 cords per season. In aggregate they account for two-thirds of the wood sold by the sampled firms. Six firms accounted for an estimated 60 percent of the 3,000 cords of fireplace wood marketed in the New Haven area in the 1963-64 season.

Strong seasonal trends are evident in retail firewood sales. Producer-retailers who market more than 50 cords per season begin selling wood in early September. Sales climb to a peak in December, and gradually fall off until the end of the sales season in early March. Merchant-retailers and producer-retailers who handle less than 50 cords per season report a more limited sales period. For them, sales begin in late November and drop off rapidly after New Year's Day.

Eighty percent of the fuelwood sold by producer-retailers is sold delivered to the consumer's residence in ½- and 1-cord units. Producer-retailers handling more than 50 cords per season specialize in these large unit sales, although small volumes of wood are sold at their place of business in smaller units such as bundles or trunkload units. Occasionally retailer-producers also sell to merchant-retailers, but this is not a regular practice and the volume is small.

Two of the merchant-retailers surveyed specialize in sales of bundles and other small units. The third sells most of his wood on a cord basis. Sales of smaller units are made at the retailer's place of business; cord sales are sold on a delivered basis.

Most half-cord and full-cord sales are initiated by the purchaser, but it is not uncommon for a retailer to solicit orders from past customers in late summer or early fall. This serves two functions. It maintains customer loyalty and enables the retailer to spread his deliveries over a longer time period, thereby cushioning the effects of heavy seasonal demand.

Wholesalers

Three firms were sampled whose principal role in the fuelwood market is that of a wholesaler. Although each sells to retail customers, the majority of sales are to retailers. Two firms are land-clearing contractors. The third is a public utility.

The operational methods of the land-clearing contractors closely parallels those of the producer-retailer. Wood is obtained in the course of land-clearing operations on a year-round basis, is converted to fuelwood-size material, and is sold. Manufacturing is done on a part-time basis throughout the year.

The main operational difference between these wholesalers and their producer-retailer counterparts is scale of operations. Each markets over 300 cords of fireplace wood per year (compared to an average of 25 cords for producer-retailers). Slightly less than half of the wood handled by these wholesalers is sold to consumers on a retail basis. Wholesale sales are made to a limited number of retailers, seldom over two or three.

The public utility's association with the fuelwood market is an outgrowth of its forest-management program for replacing hardwoods with softwoods on company lands. It is the only landowner in the New Haven area that deliberately and continuously furnishes wood to the fuelwood market. Annual sales to New Haven retailers and other wholesalers account for nearly four-fifths of the wood which moves through wholesalers in the New Haven market area and about a third of the total retail volume.

Production and sales are year-round activities. The product sold is 5-foot bolts. Bolts larger than 6 inches in diameter are split to smaller sizes in a portable log-splitter.

Prices and Costs

Prices

Retail prices.—In the 1963-64 fireplace season, average delivered retail prices were $26 per cord and $15 per half-cord. These are the prices charged by nearly all firewood retailers. Those that did not charge the market price quoted prices within $1 of it.

A bundle of wood, the most common of the smaller sales units, sells for $1 to $2. Since the number of sticks per bundle and the average size of sticks varies widely, the equivalent price per cord also varies. It ranges between $30 and $50 per cord. At the higher end of the scale, the consumer pays a substantial premium for the convenience of purchasing by the bundle.

The uniformity of cordwood prices is largely the result of a tacit agreement among larger retailers to charge the same price quoted by the largest retailer in the area. Smaller retailers cite the price charged by the larger retailers as the basis of their own charge. The leader's prices are reported to be based on a cost-plus-percentage formula.

No attempt was made to judge the fairness of the market price, but two factors indicate that the consumer does not suffer under the present pricing system. First, substantially higher prices are charged in neighboring communities.[4] Second, the leader is deliberately conservative in establishing his percentage markup.

The price leader's conservativeness and the willingness of others to follow his lead is based on a number of considerations. First, his firm has been the major supplier of fuelwood in the New Haven area for several generations. He takes pride in this fact and hopes to continue the tradition. In order to maintain his market position, he keeps his price close to his variable operating costs. On the basis of his many years of experience in the fuelwood market he feels that the amount of fuelwood consumed in the market would not be reduced significantly by even a substantial price rise (that is, demand is inelastic), but that unnecessary price rises must be avoided because of this possibility of

[4] Wood sells for $32 per cord in nearby cities and $40 per cord in communities closer to New York. At the extreme, Manhattan apartment dwellers buy firewood delivered in paper packages at the equivalent of about $75 per cord.

inducing an inrush of new supply. This, he feels, could jeopardize his market position and eventually result in market instability.

Other large-volume suppliers agree that a substantial price rise would not affect the amount of wood consumed, but disagree with the leader about the possible destabilizing effect of a substantial price rise. Nevertheless, none feel that they are in a favorable enough market position to increase their prices substantially above that of the leader. Also, each of the larger retailers agree that any serious effort to increase their market share by price-cutting would lead to a mutually detrimental price war.

The larger retailers may also be inclined to follow the leader's price because they experience about the same or lower costs of production. Each obtains about half of his wood in the form of 5-foot bolts from the same wholesaler, the remainder from small land-clearing operations. In addition, most of the major suppliers (other than the leader) use their own labor in the manufacturing process and therefore experience lower out-of-pocket production costs than those of the price leader.

This is not to say that the price of wood is stable through time. Over the past 5 years, fuelwood prices have increased 30 percent. The explanation offered by the price leader is rising labor costs, and it is supported by other firms serving the retail market. In fact, a common complaint among larger retailers is that labor costs have increased faster than the market price, and that their margin for profit has correspondingly decreased.

Non-price competition is also limited, but most sellers make of it what they can. Smaller retailers sometimes attempt to push sales with extra services such as free kindling.

Wholesale prices.—The standard wholesale price for 5-foot bolts is $14 per cord delivered to a retailer's yard or $10 per cord at roadside. The wholesale price for delivered fully manufactured and seasoned firewood ranges between $20 and $22 per cord.

Costs

Most retailers and wholesalers do not keep full records of their costs. However, one wholesaler and several of the larger pro-

ducer-retailers have supplied cost data that may be representative of the more efficient operators. According to these estimates, the total cost of producing a merchantable cord of wood at the going wage rate for woods labor is $19. This consists of $10 for the production of 5-foot bolts, $4 for delivery to the yard, and $5 for handling, bucking, and splitting the 5-foot bolts.

Seasoning costs are excluded from these calculations, but obviously are not zero. The investment in stored wood represents an opportunity cost. The size of these costs varies with the size of the operations, and no meaningful average can be derived.

Stumpage is considered a free good and therefore is also excluded from cost calculations. Producer-retailers and wholesalers obtained their raw material as a byproduct of other operations. The salvaged wood has no other known economic use. One wholesaler occasionally sells stumpage to firewood sellers who attempt to supplement other sources of supply. However, the nominal stumpage price he is able to extract from these sales is based more on his ability to provide a stable annual supply than on wood scarcity.

The above costs probably are not representative of most of the fuelwood handlers. Only those reporting costs actually pay the going wage rate for woods labor.

Income derived from firewood is either an extra coming out of some related activity such as land-clearing, nursery work, or noncommercial forest-type conversion, or is handled as a secondary or moonlighting activity. Most firewood operations involve only one or two men, and labor is often devoted to firewood because it is underemployed in other activities. Thus the full cost of firewood marketing and production is often an opportunity cost or is borne by some other activity.

Comparisons of Costs and Prices

Costs of fireplace wood procurement and manufacture are compared with prices in table 2. The margins and profit-opportunity ratios shown should be interpreted with caution. On the one hand, cost data are heavily weighted by the experience of the larger and presumably more efficient operators. On the other

Table 2.—Margin and profit-opportunity ratio for retailing and wholesaling fireplace wood in the New Haven area, 1964

Agent and product	Price received	Manufacture or procurement cost	Marketing margin	Profit-opportunity ratio[1]
	Dollars per cord			*Percent*
Retailer:				
Bundle sales	$30.00-50.00	$19.00	$11.00-31.00	37-62
Cord Sales	26.00	23.00	3.00	13
Wholesaler:				
Manufactured cord	22.00	21.00	1.00	5
5-foot bolts	14.00	([2])	—	([3])

[1] Profit-opportunity ratio is the ratio of margin to price received.

[2] Withheld to avoid disclosure.

[3] Less than 5 percent.

hand, many retailers and wholesalers use their own labor in the fuelwood-manufacturing process. The out-of-pocket production expenses for such firms are probably much lower than those shown.

Despite these limitations, the margins shown indicate the relative profitability of handling fireplace wood at different levels of involvement in marketing and manufacturing. The greatest opportunity for profit appears to be in retailing of small bundles. Such sales now account for only 10 percent of the firewood marketed in the area. Wholesalers whose principal product is green 5-foot bolts have the smallest per-cord profit-opportunity ratio.

Summary and Conclusions

The principal consumer of fuelwood in the New Haven area is the individual who burns wood in his home fireplace. In the fall and winter of 1963-64, some 3,000 cords (104 cubic feet per cord) of fireplace wood were consumed in the area. The firewood market is supplied by retailers and wholesalers who are part-time operators primarily engaged in other occupations. Ninety percent of the retail sales are made by firms that process at least a portion of the wood they sell; 10 percent is by firms that purchase merchantable wood from wholesalers.

The retail price for fuelwood is fairly uniform throughout the New Haven area, largely because of an informal agreement among retailers to follow the pricing policy of the largest retailer in the area. No attempt was made to judge the fairness of the market price, but substantially higher prices in neighboring communities indicate that the consumer does not suffer under the present pricing system.

Cost and price comparisons show that cost-price margins are greatest for retailing of small bundles of wood and least for the wholesaling of green 5-foot bolts. However, the major source of returns for most fuelwood sellers is not found in the marketing margin but rather in the return to contributed labor.

Wood that enters the New Haven fireplace wood market is salvaged from land-clearing, tree removal, or noncommercial forest-management activities of the seller. More than half of the firewood sold in the area is manufactured by producer-retailers who obtain the majority of their raw material from their own land-clearing or tree-removal activities. About 45 percent is sold by retailers who purchase hardwood bolts from wholesalers. The wholesaler in turn obtains his wood as a byproduct of other activities. Only an insignificant amount of firewood comes from stumpage harvested specifically for firewood. When this does occur, it is done only to supplement other wood sources. For the most part, raw material for fireplace wood is widely available and is a free good. It has no known alternative use.

Sixty percent of the firewood retailed has been processed by firms that handle more than 50 cords of wood per season and undertake fuelwood manufacture and marketing as a regular and planned activity. The remainder has been processed by smaller volume retailers during lulls in normal activities.

It seems probable that, as consumer firewood requirements continue to increase, the larger scale retailers will capture an even greater share of the New Haven area market. The smaller retailer is engaged in firewood production and marketing primarily as a means of utilizing the salvagable byproduct of his tree-removal operations and as a means of providing productive work for underemployed labor. The raw material available to these firms is limited by the extent of their tree-removal operations. This source could be supplemented by purchasing from wholesalers, but this is unlikely under present market conditions. With the current market structure and pricing method, a substantial increase in market price is improbable, and the smaller operator is not likely to emphasize firewood production at the expense of his regular, more profitable activities.

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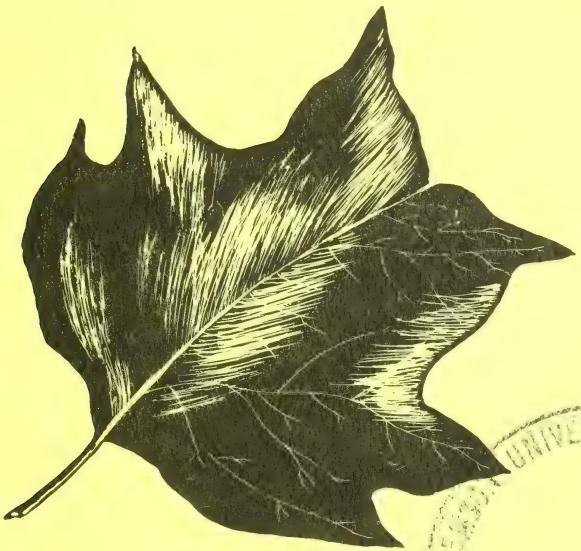
Site Index of YELLOW-POPLAR

Related to Soil and Topography in Southern New Jersey



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RICHARD D. LANE, DIRECTOR

Site Index of
YELLOW-POPLAR
Related to Soil and Topography
in Southern New Jersey

The Author

JOHN J. PHILLIPS, soils scientist, was graduated from the University of Wisconsin with a major in soils in 1956. He was employed by the Northeastern Forest Experiment Station from 1956 to 1964, where he conducted research on timber and watershed management, mostly in connection with soils. Work reported in this paper was performed while he was assigned to the Experiment Station's timber-management research unit at New Lisbon, New Jersey.

YELLOW-POPLAR (*Liriodendron tulipifera* L.) is one of the most desirable tree species in the Middle Atlantic States, but little has been known about the effects of various soil and topographic conditions on its growth in this region. In 1963 a study was begun to determine these relationships in New Jersey, Maryland, Delaware, and eastern Pennsylvania. This paper presents the findings in one small portion of this area, the Coastal Plain of New Jersey.

Yellow-poplar is limited mostly to the inner portion of the New Jersey Coastal Plain, a strip of land 15 to 20 miles wide and about 100 miles long extending along the Delaware River from Bridgeton to Trenton and then northeastward south of the fall line, which crosses New Jersey roughly from Trenton to Perth Amboy. Much of this portion of the Coastal Plain is a low-relief plain, the result of erosion and deposition. The uplands are seldom more than 60 feet higher than the stream valleys and flood plains. The slopes in between vary up to 30 percent, but the steeper slopes are short—often 200 feet or less. The relatively flat uplands often have fine-textured soils, with poorer drainage

than that found in sections with coarse soils or greater relief.

Well-drained soils in this portion of the New Jersey Coastal Plain are Gray-Brown and Red-Yellow Podzolic intergrades, derived either from old upraised ocean-bottom sediments or from younger surficial deposits of Pleistocene age. The ocean-bottom sediments consist primarily of sands, silts, and clays in varying mixtures, in most places carrying glauconite as a clay mineral. Although the younger surficial deposits include all four separates —gravel, sand, silt, and clay—they have frequently been sorted so that the coarse materials predominate in one place, silts and clays in another. The soils are usually low in fertility, high in iron, and strongly acid, generally with a pH of 4.4 to 4.8.

In this part of New Jersey, yellow-poplar occurs most commonly on the stream-cut slopes, frequently on bottomland sites, and occasionally on low-relief upland sites.

STUDY PROCEDURE

In the inner Coastal Plain, 44 plots were established in even-aged stands. Each plot included 4 to 6 dominant yellow-poplars that were 30 to 70 years old and growing on a uniform soil. Total height and age at breast height were determined for each sample tree, and the average values were computed for each plot. Total age from seed was estimated by adding 3 years to the number of rings at breast height. The site index—height at 50 years of age—was then determined from Beck's curves for the Piedmont.[1]

Data on soil and topographic factors that might affect site index were taken and handled as described below. Soils were examined to a depth of 5 feet by the use of a bucket-type auger (3 inches in diameter); 2 to 5 borings were obtained in each plot.

Soil type.—Classified for each plot according to the National Cooperative Soil Survey standards by M. L. Markley or Van R. Powley, soil scientists of the U. S. Soil Conservation Service.

[1] Beck, Donald E. YELLOW-POPLAR SITE INDEX CURVES. U. S. Forest Serv. SE. Forest Exp. Sta. Res. Note 180. 2 pp., illus., 1962.

Topographic position.—Grouped into three classes to indicate landscape position and surface drainage. Though slope, aspect, and position on slope were determined for each plot, only the following classes seemed desirable in the analysis:

(1) Poor bottomland sites: flat, poorly drained bottomlands having less than 2-percent slope and located more than 100 feet from deep-cut streams (streams where normal summer flow is 3 feet or more below the banks). Bottomland, as used here, is a topographic position in that it includes alluvial and residual soils. Some stream valleys that are seldom subject to overflow are included. All areas where stream surfaces approach the level of soil surfaces fall in this class.

(2) Good bottomland sites and the lower 25 percent of stream-cut slopes: bottomland sites with 2-percent or more slope or less than 100 feet from a deep-cut stream, and the lower 25 percent of stream-cut slopes.

(3) Mid and upper portions of stream-cut slopes and occasional upland sites: The upper 75 percent of stream-cut slopes and occasional upland sites where yellow-poplar occurs.

Depth to tight subsoil.—Measured in inches in each hole and averaged for the plot. A tight subsoil was any strongly developed moderately fine layer resulting from a relatively high clay content (usually 18 percent or more). These layers often occurred in the B_2 horizon. None of the tight subsoils encountered were considered to be fragipans. In the analysis, soils with depths to tight subsoil of 36 inches or slightly more did not differ in site index from those with no tight subsoil within 5 feet, so all such values were grouped into one class and given the value of 36 in developing the regression equation. Depth to tight subsoil did not fall between 32 and 36 inches on any of the soils sampled, so the effect of such depth on site index cannot be confidently predicted from the results of the study.

Depth to mottling and depth to each soil horizon.—Measured in inches in each hole and averaged for the plot. While depth to mottling was easily measured in most plots, it was obscured in some poorly drained soils and in all very poorly drained

ones by a thick black A_1 layer. Where this occurred, mottling was considered to extend to the soil surface. Justification for such a procedure is found in poorly drained soils with gray A_1 layers where mottling often occurs at 2 or 3 inches from the surface.

Soil texture.—Determined for each plot from samples collected of the A horizon and of the finest-textured layer within 36 inches of the soil surface. The latter layer was usually the B_2 horizon. In soils having no noticeable change in texture within 36 inches, the depth between 24 and 36 inches was used as the subsoil in texture analyses. These analyses were made by the Bouyoucos hydrometer method as modified by Wilde and Voigt,[2] except that samples were allowed to rehydrate overnight in the dispersing solution.

pH of A horizon and pH of subsoil.—Determined by using a simple colorimetric pH kit.

RESULTS

Regression Analysis

By regression analysis, an equation was derived that expressed site index in relation to several soil and topographic factors. This equation is:

$$\text{Site index} = 88.1 + 0.739X_1 - 0.686X_2 + 0.555X_3 - 0.140X_4 + 3.558X_5 - 1.288X_6 - 18.374X_7$$

X_1 = depth to mottling, in inches.
X_2 = $(X_1)^3 \div 1{,}000$.
X_3 = percent clay in subsoil.
X_4 = $(X_3)^3 \div 1{,}000$.
X_5 = 1 (for poor bottomland sites).
= 2 (for mid and upper portions of stream-cut slopes and occasional upland sites).
= 3 (for good bottomland sites and the lower 25 percent of stream-cut slopes).
X_6 = 36 inches minus depth to tight subsoil, in inches.
X_7 = 0 (if tight subsoil is less than 36 inches from the soil surface).
= 1 (if tight subsoil is 36 inches or more from the surface).

[2] Wilde, S. A., and G. K. Voigt. ANALYSIS OF SOILS AND PLANTS FOR FORESTERS AND HORTICULTURISTS. 117 p., illus. J. W. Edwards, Inc., Ann Arbor, Mich., 1955.

This equation explains 67 percent of the variation in site index (R=0.82) and has a standard error of estimate of ± 5.5 feet. The equation predicted site index within ± 5 feet for 70 percent of the plots in this study. However, 14 percent of the plots differed from the predicted site index by 8 feet or more; maximum difference observed was 13 feet.

Table 1 gives site-index values derived from the equation. With this table, and appropriate knowledge of the soil and topographic factors of a given area, the site index can be estimated.

Table 1.—Site index for yellow-poplar on soils of the inner Coastal Plain of New Jersey[1]

A

Depth to mottling (inches)	Percent of clay content of B_2 horizon (or 24- to 36-inch depth)									
	5	10	15	20	25	30	35	40	45	50
0	91	94	96	98	100	101	102	101	100	98
5	94	97	100	102	103	105	105	105	104	102
10	98	100	103	105	106	108	108	108	107	105
15	100	102	105	107	109	110	110	110	109	107
20	100	103	105	107	109	110	111	111	110	108
25	99	101	104	106	108	109	109	109	108	106
30	95	97	100	102	103	105	105	105	104	102
35	87	90	92	95	96	97	98	98	97	95
40	77	79	82	84	85	87	87	87	86	84

B

Depth to tight subsoil (inches)	Topographic position and surface drainage		
	Good bottomland sites and lower slopes	Mid and upper slopes and upland sites	Poor bottomland sites
10	−23	−26	−30
15	−16	−20	−23
20	−10	−13	−17
25	− 3	− 7	−11
30	+ 3	− 1	− 4
36-60[2]	− 8	−11	−15

[1] First obtain base value in A; then correct as indicated in B. Estimated site index is the result of adding these two values.

[2] Includes plots with no tight subsoil within the 5-foot zone sampled.

Discussion of Individual Variables

Soil Factors

Depth to mottling (X_1 and X_2).—This variable has a curvilinear relationship with site index. Site index increases 9 feet with increasing depth to mottling from zero (soil surface) to 20 inches. With greater depths to mottling, site index declines so that, according to the equation, its effect reaches zero at a depth of about 33 inches and becomes negative for greater depths.

In general, this variable has less effect on site index than the author expected. Auten[3] found a much larger difference due to poor drainage, possibly because he was dealing with soils of finer texture than those of our study.

Percent clay in subsoil (X_3 and X_4).—Site index increases sharply with clay content of the subsoil from 3 to 30 percent, then levels off with a peak at 36 percent, and apparently declines at clay contents above 40 percent. The maximum clay content found was 46 percent. Maximum change in site index due to this variable is about 12 feet.

Depth to (and presence of) tight subsoil (X_6 and X_7).—Soils with a tight subsoil at depths of 22 inches or less form relatively poor sites. Site index increases as depth to tight subsoil increases up to 32 inches at least.[4] Soils with a tight subsoil slightly deeper than 36 inches seem similar to those with no tight layer within the 5-foot depth sampled (preceding statement based on 2 and 12 plots, respectively). Both form poorer sites than those that have tight subsoils between 23 and 32 inches of the surface. These results agree fairly well with Auten's conclusion that soils must have a depth to tight subsoil of 24 inches or more to be classified as good sites for yellow-poplar.

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[3] Auten, John T. PREDICTION OF SITE INDEX FOR YELLOW-POPLAR FROM SOIL AND TOPOGRAPHY. J. Forestry 43: 662-668, illus., 1945.

[4] Equation shows values increasing to 35 inches and then dropping sharply; but depths between 32 and 35 inches were not sampled.

Topography

As already mentioned, topographic differences in the Coastal Plain are relatively minor. They result either from stream dissection of the Plain or from differences in erodibility of the various types of sediments. In much of the New Jersey area the topographic change induced by these factors is less than the 25-percent slope or 50-foot difference in elevation Auten found to be necessary before topography has an important effect on site index in the Central States.

However, two topographic factors—landscape position and surface drainage—have significant effects on the site index of yellow-poplar in the New Jersey Coastal Plain. Together, these account for a variation of about 7 feet in site index.

Other factors being equal, the best sites were those on the lower portions of stream-cut slopes and in bottomlands where deep-cut streams within 100 feet or slopes of 2 percent or more provided good surface drainage. Site index there was about 7 feet more than on relatively flat bottomlands where the lack of slope and absence of nearby deep-cut streams provided poor surface drainage. The latter sites were also about 3.5 feet poorer than those sampled on mid or upper slopes and on uplands.

Soil Series

The site-index values for various soil series are shown in table 2. In general, not enough data are available to properly assess the value of soil series in estimating yellow-poplar site index.

Even with drainage classes there is no clearcut relationship. Site indexes on soils classified as well drained varied from 78 to 108, while in the combined groups of moderately well to somewhat poorly drained soils the variation is almost the same: 79 to 110 (table 2). Apparently on the poorer drainages site index does decrease, especially on the finer-textured soils. However, on some poorly and very poorly drained soils with sandy or loamy textures site indexes between 90 and 100 were measured (table 2).

Table 2.—Site index by soil series[1]

Drainage class and soil series	New classification	Plots	Range (average) site ind
		No.	*I*
	WELL DRAINED SOILS		
Collington	Alfic Normudults; fine loamy, mixed, mesic.	1	
Downer	Alfic Normudults; coarse loamy, siliceous, mesic.	1	
Freehold	Alfic Normudults; fine loamy, mixed, mesic.	5	78-108 (
Matapeake	Alfic Normudults; fine silty, mixed, mesic.	1	
Sassafras	Alfic Normudults; fine loamy, siliceous, mesic.	3	78-100 (
Westphalia	Typic Normudults; coarse loamy, siliceous, mesic.	1	
Westphalia-Freehold[3]	(See above series descriptions)	1	
Westphalia-Lakeland[4]	(Lakeland: Typic Quartzipsamments; sandy, siliceous, acid, mesic[5] for Westphalia see above.)	2	88-88 (
Mixed Sandy Colluvium		1	
	WELL TO MODERATELY WELL DRAINED SOILS		
Adelphia-Marlton	Adelphia: Aqualfic Normudults; fine loamy, mixed, mesic; for Marlton, see below.	1	
Howell	Typic Normudults; clayey, mixed, mesic.	3	89-103 (
Marlton	Typic Normudults; fine, mixed, mesic.[2]	1	
Matawan	Aqualfic Normudults; fine loamy, mixed, mesic.	1	
	MODERATELY WELL DRAINED SOILS		
Keyport	Paraquic Normudults; clayey, mixed, mesic.[2]	1	
Klej-Nixonton[4]	(Klej: Aquic Normi psamments; sandy, siliceous, mesic; Nixonton—see below.)	2	88-90 (
Mattapex	Aqualfic Normudults; fine silty, mixed, mesic.	1	

CONTINUED

TABLE 2, CONTINUED

Drainage class and soil series	New classification	Plots	Range (and average) in site index
		No.	*Feet*
Nixonton	Aquic Dystrochrepts; coarse silty, mixed, mesic.[5]	1	87
Woodstown	Paraquic Normudults; fine loamy, siliceous, mesic.	1	82
MODERATELY WELL TO SOMEWHAT POORLY DRAINED SOILS			
Holmdel	Paraqualfic Normudults; fine loamy, mixed, mesic.[2]	5	81-102 (91)
SOMEWHAT POORLY DRAINED SOILS			
Barclay	Aquic Dystrochrepts; coarse silty, mixed, mesic.	2	86-105 (96)
Bertie	Aqualfic Normudults; fine loamy, mixed, mesic.[2], [5]	1	110
Lenoir	Aquic Normudults; fine, mixed, mesic. [2], [5]	1	98
POORLY DRAINED SOILS			
Pasquotank	Typic Normaquepts; coarse silty, mixed, acid, mesic.[5]	1	82
Loamy alluvial lands		2	91-100 (96)
VERY POORLY DRAINED SOILS			
Sandy alluvial lands		3	72-85 (80)
Muck, sand surface		1	97

[1] Soils classified by M. L. Markley and V. R. Powley, U. S. Soil Conservation Service.

[2] Classification tentative, not correlated.

[3] Slightly glauconitic surface overlying loamy fine sands.

[4] Uniform fine sands to fine sandy loams with discontinuous B horizons. When present, these B horizons are only slightly finer-textured than overlying horizons.

[5] Type location is in thermic, not mesic, zone.

DISCUSSION AND CONCLUSIONS

This study indicates that yellow-poplar grows best on soils with deep, well-drained surface layers overlying loamy or moderately fine-textured subsoils with a good supply of available moisture. The last is indicated by the importance of mottling and of favorable topographic positions (lower slopes and bottomlands with good surface drainage). Conversely, the poorest growth, although no yellow-poplars were found there, would be on flat-lying, poorly drained soils with shallow depths to tight subsoil. Except for the desirability of a mottled subsoil, the findings are in accord with the commonly accepted generalizations of the site requirements for the species. Apparently poor aeration in the subsoil—for some periods of the year at least—is less harmful than is lack of moisture.

Although yellow-poplar roots were found throughout the 5-foot soil depth studied, neither mottling in the 3-to-5-foot zone nor presence of a tight layer there affected site index. However, it is possible that conditions in this zone were reflected in other factors.

Yellow-poplar is commonly found on fine-sand soils, but seldom found on the coarser sand soils. Size of particles in the sand fraction did not appear as a significant variable in this study because no measurable stands could be located on well-drained coarse sand soils. Hence, this equation should not be applied to such soils.

SUMMARY

Yellow-poplar grows rapidly on the deep, moist soils of New Jersey's inner Coastal Plain, attaining heights of 70 to 110 feet at 50 years of age. Factors related to height growth are depth to mottling, depth to tight subsoil, clay content of the subsoil, topographic position, and surface soil drainage. The resulting equation explains about 67 percent of the observed variation in site index.

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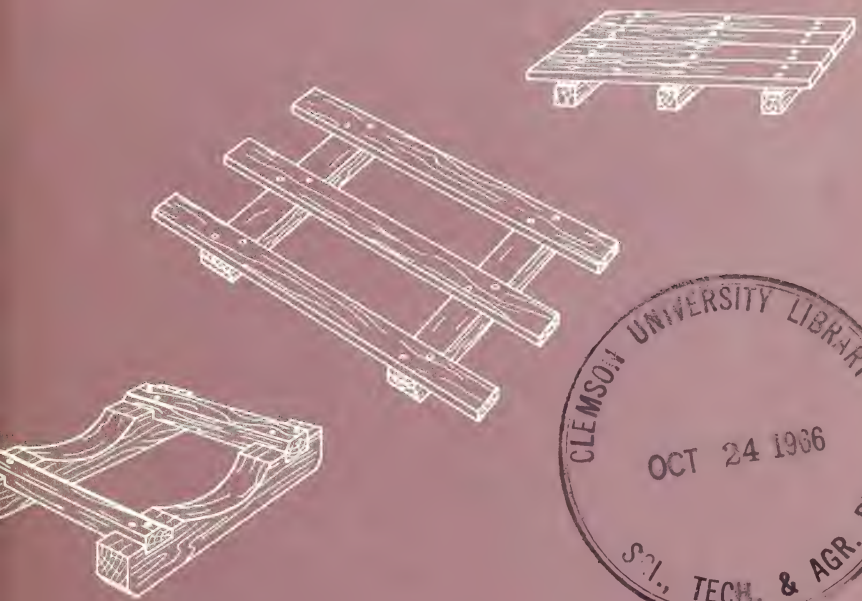
The market for WOOD PALLETS in the steel industry

by Tony C. Carlson



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TONY C. CARLSON, forest products technologist, received his Bachelor of Science (1962) and Master of Science (1964) degrees in forestry, specializing in wood utilization, from the University of Montana. After a year of teaching there, he joined the staff of the U. S. Forest Service's Northeastern Forest Experiment Station, Forest Products Marketing Laboratory, Princeton, West Virginia, as associate market analyst. He has since completed some of the work toward a Ph.D. at the University of Michigan.

The market for WOOD PALLETS in the steel industry

A Growing Industry

FROM almost nothing before World War II, the wood pallet industry has grown into a $220-million-per-year industry. It now provides the third largest market for domestic hardwood lumber. In 1963 it consumed nearly 1.3 billion board feet — more than 17 percent of the total national hardwood lumber production.[1] While serving nearly every other manufacturing industry, the wood pallet industry has also become important to the economies of forest-dependent communities in the hardwood region.

We know about some of the general problems of pallet manufacture, marketing, and use; and we know that demand is probably growing faster for wood pallets than for any other major lumber product.[2] Yet except for one study[3] we have little specific information about the characteristics of the various pallet markets. To maintain and expand the pallet industry, and to facilitate efficient utilization of the forest resource, we need to know more about the individual markets for wood pallets.

[1] Based on annual statistics of the National Forest Products Association and the National Wooden Pallet Manufacturers Association.

[2] Lucas, J. T. A PROBLEM ANALYSIS OF THE WOOD PALLET INDUSTRY. Unpublished report on file at the U. S. Forest Products Marketing Laboratory, Princeton, W. Va. 61 pp., illus., 1965.

[3] Sutherland, C. F., Jr. THE MARKET FOR WOOD PALLETS IN THE AUTO INDUSTRY — A CASE STUDY OF THE FORD MOTOR COMPANY. U. S. Forest Serv. Lake States Forest Exp. Sta. Paper 104, 10 pp., illus., 1962.

The Study

To examine the extent, stability, and opportunities for expansion of the market for wood pallets in the steel industry, a study was undertaken by the Forest Products Marketing Laboratory of the U. S. Forest Service's Northeastern Forest Experiment Station.

The wood pallet market cannot be considered as a homogeneous unit to be studied in its entirety. Each industrial segment served by the pallet industry has its own peculiar market characteristics and unique marketing problems. Therefore, these segments should be examined separately.

The steel industry was selected for investigation because it comprises the major part of the fourth largest industrial user of wood pallets (fig. 1) and because it offers a concentrated and

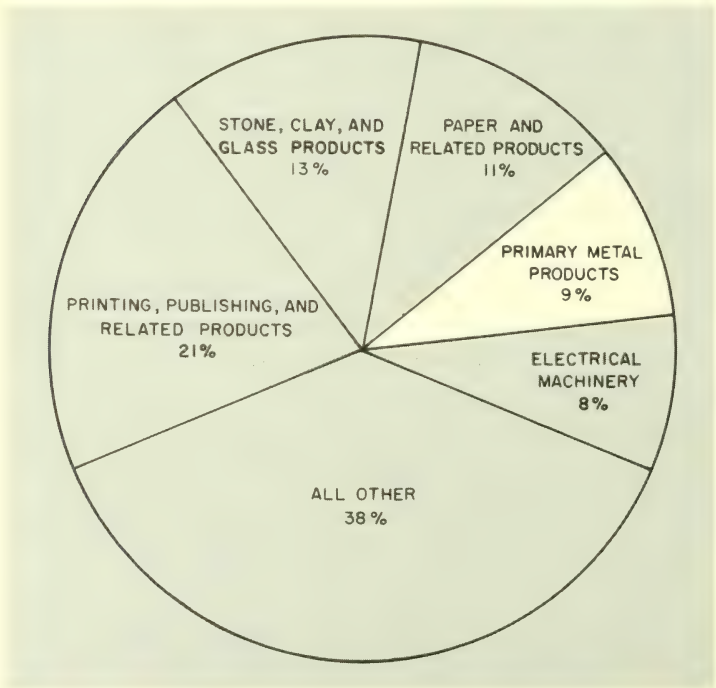

STONE, CLAY, AND GLASS PRODUCTS 13%
PAPER AND RELATED PRODUCTS 11%
PRIMARY METAL PRODUCTS 9%
ELECTRICAL MACHINERY 8%
ALL OTHER 38%
PRINTING, PUBLISHING, AND RELATED PRODUCTS 21%

Figure 1. — Use of wood pallets by manufacturing industries in the United States, 1960. Source: Gill, T. G., WOOD USED IN MANUFACTURING INDUSTRIES; U. S. Forest Serv. Statist. Bull. 353, 1965.

Table 1. — Important concentrations of steel rolling and finishing mills in the United States[1]

State	Major cities	Number of firms		Number of employees
		Total	Firms with 20 or more employees	
Pennsylvania	Bethlehem Pittsburgh	69	53	100,000
Ohio	Akron Cleveland Youngstown	80	76	93,000
Indiana	Gary	26	24	58,000
Illinois	Chicago	71	52	45,000
New York	Buffalo	51	32	32,000
Michigan	Detroit	31	29	21,000
Alabama	Birmingham	21	21	21,000
California	Los Angeles San Francisco	61	39	19,000
West Virginia	Weirton Wheeling	14	11	16,000
Massachusetts	Worcester	39	31	6,000
Kentucky	Louisville	8	8	6,000

[1]States with more than 5,000 employees in the study category (SIC 331). Source: U. S. Department of Commerce, Census of Manufacturers vol. III, Area Statistics, 1958.

specialized market for pallet producers in the Appalachian Region (table 1).

Nine of the largest steel corporations in the United States were studied. Their combined production accounts for about 73 percent of the total American steel product output and, as nearly as could be determined, they use at least that percentage of the steel industry's wood pallets.[4, 5] So although the sample is not truly representative of the entire steel industry in size of firm, the unsampled portion is composed principally of the smaller mills, which, it has been assumed, follow the general pattern of the leaders in pallet use.

[4]United States Bureau of the Census. 1958 CENSUS OF MANUFACTURES. VOLUME 1: SUMMARY STATISTICS. Washington, D. C. 1958.
[5]Editors of Fortune. THE FORTUNE DIRECTORY. Time, Inc., N. Y. 40 pp., 1964.

The nine firms were sampled in three steel-producing states: Ohio, West Virginia, and Pennsylvania. Their operations here were reported to typify the pallet-using policies of other steel centers as well. Most of the sample companies have mills in several geographically separate areas; and among these plants, pallet use and purchasing practices are consistent. Therefore, no geographic bias is expected.

To obtain the required data, purchasing officers in the nine firms were personally interviewed. Emphasis was focused on obtaining the customer's point of view because it was felt that his products, problems, and attitudes finally determine the salability and market characteristics for wood pallets.

Since there is no clear distinction among the various types of industrial platforms, the term *pallet,* as used here, also means all units that might otherwise be called bases or skids.

The Present Market

The term *steel industry* as used in this paper is best defined by the Census Bureau's standard industrial classification (SIC) 331: blast furnaces, steel works, and rolling and finishing mills. Gill's statistics on wood-product consumption indicate that this industry used about 69 million board feet of lumber for pallets in 1960.[6]

Collectively, the nine sampled firms consumed about 59 million board feet of lumber for pallets in 1964. Based on this estimate, and assuming that the level of pallet use is proportional to company size, the entire steel industry used approximately 81 million board feet of pallet lumber in 1964, nearly all of which was hardwood. This amounted to about 1.9 board feet of lumber per ton of palletizable steel product.

The present market for wood pallets in the steel industry is characterized by four main features: pallet style and size, expendability of pallets, number and type of pallet producers, and the problem of who makes the pallets (fig. 2). On the one hand, these

[6]Gill, T. G. WOOD USED IN MANUFACTURING INDUSTRIES. U. S. Forest Serv. Statist. Bull. 353, 121 pp., 1965.

characteristics affect classical market forces and functions such as price, channel of distribution, and storage; and they are in turn influenced by several factors of both the pallet and steel industries.

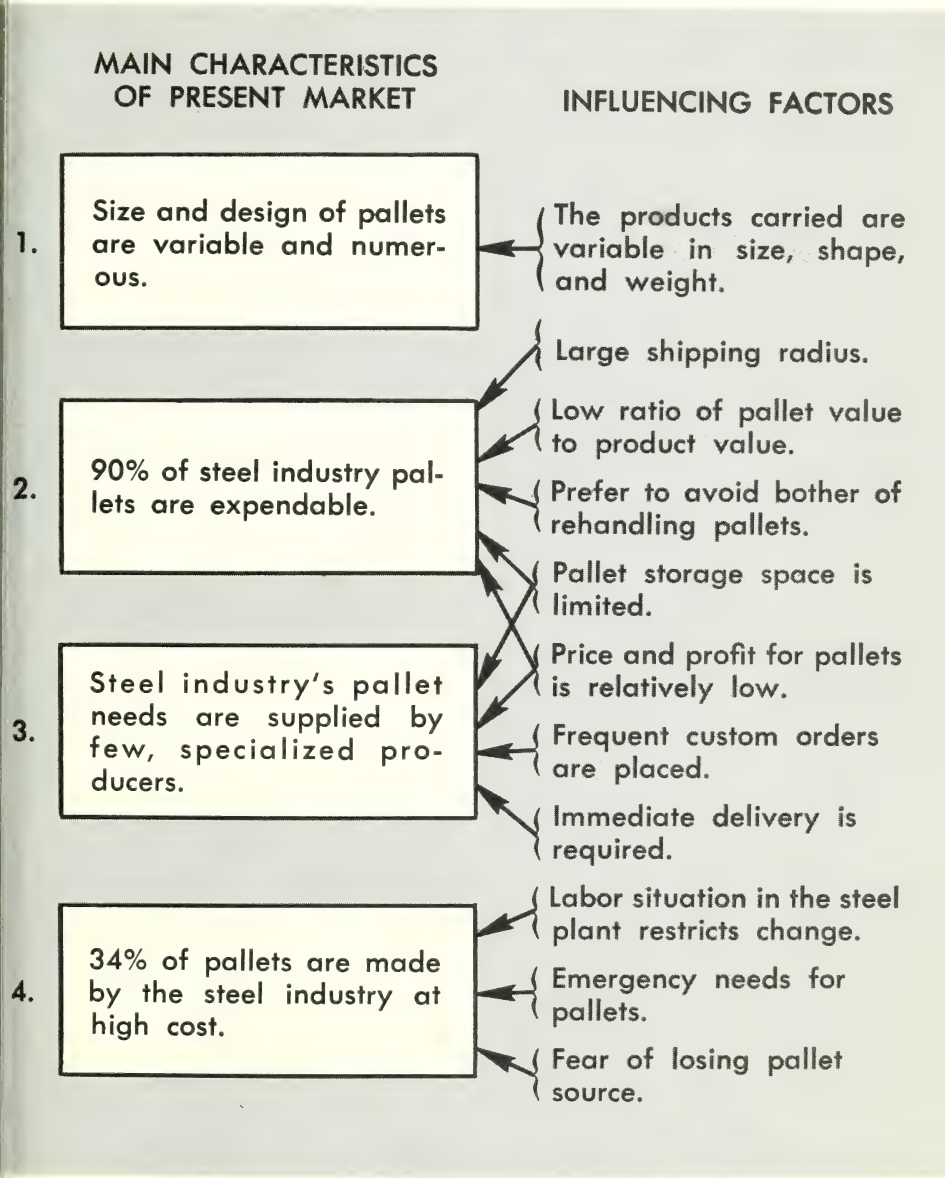

MAIN CHARACTERISTICS OF PRESENT MARKET
INFLUENCING FACTORS
1. Size and design of pallets are variable and numerous.
The products carried are variable in size, shape, and weight.
2. 90% of steel industry pallets are expendable.
Large shipping radius.
Low ratio of pallet value to product value.
Prefer to avoid bother of rehandling pallets.
Pallet storage space is limited.
Price and profit for pallets is relatively low.
3. Steel industry's pallet needs are supplied by few, specialized producers.
Frequent custom orders are placed.
Immediate delivery is required.
4. 34% of pallets are made by the steel industry at high cost.
Labor situation in the steel plant restricts change.
Emergency needs for pallets.
Fear of losing pallet source.

Figure 2. — Factors affecting the characteristics of the market for wood pallets in the steel industry.

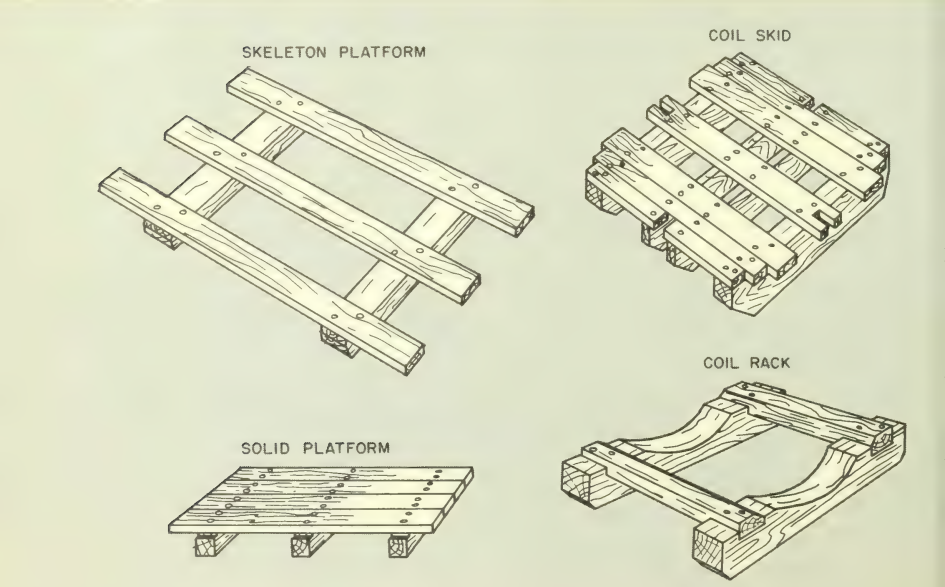
PALLETS USED

Variability and Products Carried

The style and size of pallets used in any establishment are determined mainly by the product to be carried. As it happens, palletizable products of the steel industry vary greatly in size and shape and, as a result, the design of pallets also varies — so much, in fact, that one company said it uses as many as 1,700 different style-size combinations. Besides the common double-faced warehouse pallet, as many as 30 other styles of wood platforms are in use — all in several sizes. So the wood pallet is essentially a custom item in the steel industry.

The more primary segments of the steel industry have little use for pallets: ingots, bars, rails, and pipe are so heavy and unwieldy that they are usually handled individually and not palletized. The greatest users of pallets are the mills that produce flat or formed rolled stock such as plain, galvanized, coated, or electrical sheet; strip metal; tin plate; and corrugated roofing.

Figure 3. — Examples of wood pallets used in the steel industry.



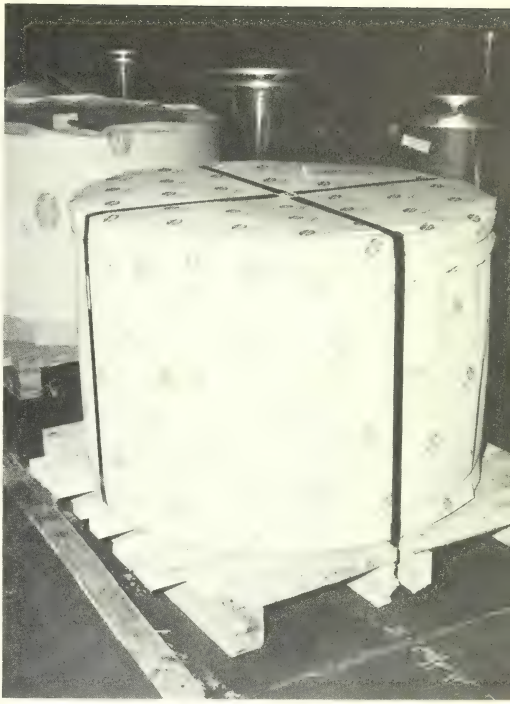


Figure 4. — Palletized steel products on wood pallets. Left, tin plate cut lengths on solid platforms. Right, tin plate coils on coil skids. (Photos by courtesy of Wheeling Steel Corporation.)

These products are handled both as cut-to-length sheets and in coils. The cut stock is stacked and palletized in loads that may weigh up to 5 tons. Coils commonly weigh as much as 10 to 15 tons and require specially designed platforms called coil skids (fig. 3). The coil skids comprise about 10 percent of the pallets used in the industry. Use of two common types of pallets is illustrated in figure 4.

Usual destinations for palletized loads of the rolled steel products are secondary manufacturers such as can companies and stamping mills.

Several other products are palletized in the steel industry, although not to the extent of the rolled sheet material. These include items such as drawn wire, nails, staples, and fencing stock.

Expendability

Pallet buyers reported consistently that about 90 percent of their wood pallets are the one-trip expendable type. Only certain types of coil skid are considered returnable by most companies; $6 is paid for the return of a $12 platform in good condition. Pallets are also considered returnable when they can be gathered and returned in carload lots, sorted by size and style. But this happens only occasionally in companies that ship a large number of a particular size of pallet load to a single steel buyer. In one such case, 40¢ was paid for returned pallets that cost about $1.50 new.

Although most pallets are not returned to the steel mills, they may be reused or burned by the receiver — and most probably are burned. These expendable platforms generally arrive in good condition because quality, especially strength, is important in their manufacture. Strength is almost always a design criterion, regardless of other factors, because of the heavy loads and high value of the product carried.

Several reasons were given for the high percentage of expendable pallets used. First, pallet storage space in the steel mills is limited. And with the large number of pallet variations needed, accumulation of a working inventory of each type would be virtually impossible. The largest pallet inventory mentioned was 300 to 400 pallets, a negligible amount compared with the number used.

Second, most steel mills service a variety of customers over a rather large shipping radius. Under these conditions, it would be difficult and costly to maintain control of a pallet-return program.

Third, the value of the pallet is low in relation to the value of load carried. Therefore it is considered to be a minor cost item when viewing the load and pallet as a unit. The relatively low initial price of the pallet allows it to remain an expendable item.

A fourth factor is probably quite important in influencing the decision to use expendable pallets: most mills simply do not want to be bothered with rehandling. Consequently, these pallets are expendable by virtue of business policy, not on the basis of quality.

Besides the stated advantages, using expendable pallets may have other effects. On the positive side, the use of low-quality raw material, which seems to be in abundance, is increased by manu-

facture of expendable pallets. More raw material is consumed than if the product were reusable. This is desirable considering the viewpoints of sawmill operators, pallet producers, and resource managers toward efficient raw-material utilization. On the other hand, the image of all pallets could be affected negatively because expendable items tend to be viewed as being of rather low quality.

Specifications

Besides dimensions, the most common pallet specification issued by the steel industry concerns the type of nail to be used. Helically threaded or annular grooved nails are usually called for.

Air-dry lumber is usually specified for deckboard material because water from green deckboards might bleed through into expensive packages and cause rusting or tarnishing of the steel products. This was so important in one plant producing lithographic sheet that steel pallets were used for in-plant transport and storage. The only requests for particular species turned out to be indirect moisture-content specifications: three of the largest users require deckboards made of gum (presumably *Nyssa sylvatica)* because it could be obtained air-dry and because it does not check so badly as oak. However, most of the companies requested mixed hardwoods.

Although all companies issue some quality specifications, these specifications are rather loose, and only one firm reported that it stipulates limits for defects in the pallet parts. The situation can be summed up in the statement of one respondent: "There are few really direct specifications given—just an understood level of quality. If nails are popping or too many checks occur, we just tell the supplier and he figures out what to do about it." The procedure seems to be effective as long as close interindustry relations are maintained.

Prices

The platforms for cut-sheet products represent about 90 percent of the pallets used in the steel industry. They vary in price, depending on design, from about 90¢ to $5 (11 to 17¢ per board foot).

Design and price of coil skids are less variable. Differences in the

few main styles depend on whether the eye of the coil is placed vertically or horizontally. The most common coil skid (eye vertical — see figures 3 and 4) is used almost universally and is exchanged freely among companies. It costs about $12. One firm pays $22 for a special type of heavy-duty skid.

All companies considered current prices to be fair and would not be willing to pay more for a better platform because, "We get what we want now." In other words, the customer is making his needs known and the supplier is meeting them.

USER-SUPPLIER RELATIONSHIPS

Purchasing Practices

Only minimal pallet inventories are maintained at the steel mills, so pallet orders are placed with manufacturers as fast as requests for palletizable steel products are received. Nearly all the mills that purchase pallets order at least twice a week; more than half order daily. Receipt of pallets at the steel mill is sometimes expected within hours of an order. This practice places a great burden of service on the pallet manufacturer: he must be able to supply on very short notice any of the numerous designs and sizes of platform.

The implications of this procedure are clear. To provide this specialized service, the pallet manufacturer is rarely located more than 30 miles from the steel mills he serves. And he must have a versatility of operation that enables him to fill the frequent, diverse, and hurried orders that come in.

All but one of the respondent firms bought directly from the pallet manufacturer; over 95 percent of the pallets purchased were procured in this way. It was stated that the level of service required of pallet suppliers demands close liaison between industries. The only company to complain of service and quality problems was one who purchased pallets through brokers.

Number of Suppliers

As a result of the demand by steel companies for hard-to-render services, a small number of manufacturers successfully dominate the pallet supply side. These are the few pallet producers who are

strategically located and equipped to supply their high-service, low-margin product.

The rather stable interdependence that has developed between the two industries appears to reduce the opportunities for other wood pallet manufacturers to enter and sustain themselves in the steel-industry market. Although most steel mills reported that they do search out other pallet sources, they tend to retain present suppliers who have proved themselves able to provide the necessary services. Therefore, it may be difficult for outside pallet producers to compete with those already established.

Most steel-company purchasing offices had been visited by several pallet manufacturers who, for the most part, did not seem to be effective salesmen. A common statement in this respect was, "They know how to make pallets but don't know how to sell them. They seem to be afraid to sell their products." This viewpoint indicates that opportunities may exist for improving the pallet market by improving salesmanship and by maintaining more direct sales contacts with steel-industry customers.

MAKE OR BUY?

In 1964 about 66 percent (53 million board feet) of the steel industry's pallets were purchased in finished form. The remainder (28 million board feet) were made within the steel mills.

In pursuing the question of why steel manufacturers are in the business of making pallets, only one firm expressed a real desire to continue doing so. Purchasing agents agreed that homemade pallets cost steel companies up to twice as much as those purchased from independent pallet manufacturers. For profit and cost-conscious organizations such as steel firms, production of large quantities of wood pallets at unnecessarily high cost is rather difficult to understand. The reasons given for making pallets in the steel mills were to satisfy special rush orders or special designs and to hedge against loss of outside pallet sources. The fact remains that this practice is admittedly uneconomical, and it may present pallet manufacturers with opportunities to extend their markets.

Circumstances leading to the present practice go back to the beginning of large-scale pallet use in the steel industry, when there

were few commercial sources of pallets. Small carpenter shops were set up in the steel mills and some mills even established complete box factories. Since operation of these shops was usually intermittent, the labor force often consisted of union steelworkers. As the demand for palletized material grew, the operations became continuous; and at present, labor policies restrict the replacement of these men by the unskilled labor commonly used in independent pallet plants. Consequently, respondents said that the extra cost of platform production by steel mills is due mostly to higher labor costs.

The Outlook

The role of wood in this market seems assured. Steel-industry officials expressed a high level of satisfaction with the pallets they receive. They consistently referred to expendability and adaptability to fabrication as the factors that favor wood as the best raw material for pallets. Most of the sample firms have considered and experimented with other materials such as steel, plastics, and fiberboard; but in all cases these materials were considered too costly to merit use.

Figure 5. — Changes in production of palletizable steel products, 1959-64.

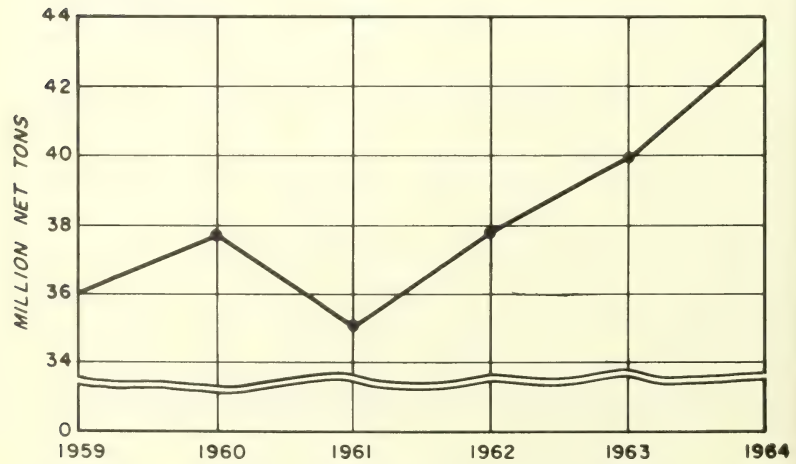


Table 2. — Shipments of palletizable steel products in the United States, 1959-64

(In millions of net tons)

Product	1959	1960	1961	1962	1963	1964
Rolled products:						
Hot-rolled sheets	7.8	8.0	7.0	7.8	8.8	9.9
Cold-rolled sheets	12.7	14.5	12.2	13.5	14.5	15.7
Galvanized sheets	2.7	3.1	3.3	3.5	3.9	4.4
Coated sheets	.3	.3	.3	.3	.4	.5
Electrical sheets	.6	.6	.5	.6	.5	.6
Strip	2.6	2.7	2.5	2.8	2.9	3.0
Black plate	.6	.6	.5	.5	.4	.4
Tin plate	5.2	5.5	5.6	5.6	5.4	5.7
Wire products:						
Drawn wire	2.7	2.4	2.4	2.5	2.5	2.5
Nails and staples	.4	.3	.3	.3	.3	.3
Other	.2	.2	.3	.3	.3	.3
Total	35.8	38.2	34.9	37.7	39.9	43.3

Source: American Iron and Steel Institute. Form AIS-16: Shipments of steel products by market classifications. 1959-64.

Barring new innovations and drastic changes in the present market structure then, the use of wood pallets in the steel industry will undoubtedly increase as production of palletizable goods increases. Although no estimates of future production of palletizable steel products are available, statistics for the last 6 years reveal a definite rising trend (fig. 5 and table 2). The average increasing rate of production for palletizable steel products has been about 4 percent per year over the 6-year period. If the trend can be taken as an approximation of normal growth, and if it continues for the next 5 years, pallet use in the steel industry could rise from the present level of 81 million board feet to 104 million board feet by 1970.

A longer-range indication of what the future might bring is the Forest Service projection of total demand for wood pallets (fig. 6). Assuming that steel mills will retain their current share of the pallet market, continuation of this trend could mean an annual steel-industry consumption of 154 million board feet of pallet lumber by the year 2000.

The opportunities for pallet manufacturers to enter or increase

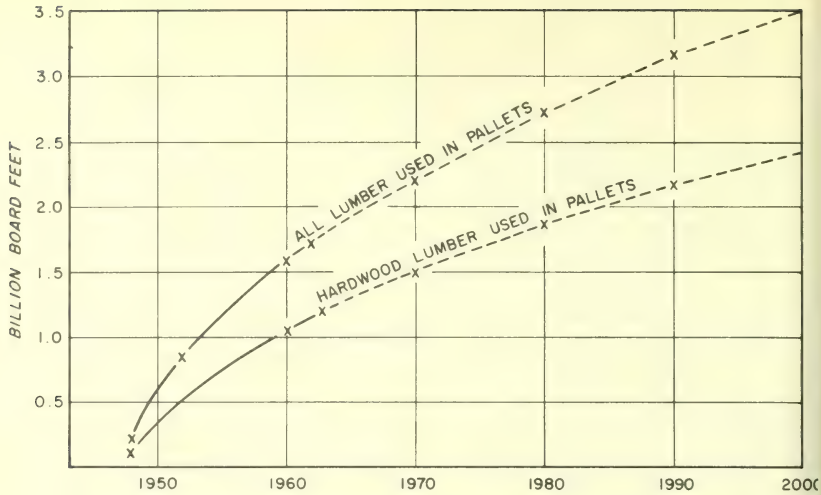


Figure 6. — Projection of total wood pallet use in the U. S. Source: U. S. Forest Service, TIMBER TRENDS IN THE UNITED STATES. U. S. Forest Serv. Forest Resource Rep. 17, 235 pp., 1965.

operations in the steel industry market appear to hinge on exploiting two of its characteristics:

- By maintaining the quality of pallets and the favorable status of wood, they can take advantage of increasing manufacture of palletizable steel products.
- Through better salesmanship and more direct sales contact with steel-mill customers, they may be able to invade the "home-made" pallet market; that is, to substitute, at a cost advantage, commercial pallets for pallets made in the steel mills.

An excerpt from a recent article on industrial-materials handling indicates a prevailing attitude that could affect all future pallet markets: "It took a lot of doing to introduce the pallet, which allowed mechanical handling. The next step may be to move from the pallet to some standardized form or forms of unit load so that greater savings may be had . . . then, of course, the pallet as we know it can be eliminated." [7]

[7] Berkwitt, G. J. MATERIAL HANDLING — A LOOK AT THE FUTURE. Mill and Factory 74(11): 91-100, 1964.

And this statement is essentially fair, for wood pallets could not long survive in competition with truly superior products. Although superiority of substitutes has not been shown, they are becoming more competitive; and the wood pallet industry can expect to maintain and accelerate its economic growth only by continual improvement of production efficiency, product quality, and merchandising techniques.

■

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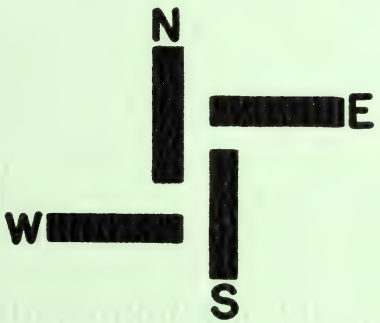
Germination & Growth of **PAPER BIRCH & YELLOW BIRCH** in Simulated Strip Cuttings

by David A. Marquis



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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

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Germination & Growth of PAPER BIRCH & YELLOW BIRCH in Simulated Strip Cuttings

TO ENCOURAGE REGENERATION

SEED germination and seedling establishment of paper birch (*Betula papyrifera* Marsh.) and yellow birch (*Betula alleghaniensis* Britton) are most satisfactory where there is abundant soil moisture and freedom from excessively high soil temperature. In a cutover forest, these conditions occur most frequently in areas shaded from direct sunlight and on scarified seedbeds that contain exposed mineral soil (*1, 4*). Attempts to encourage birch regeneration, then, could logically take two forms: use of cutting methods that provide the optimum degree of shade, and/or seedbed preparation. The study reported here deals with the first possibility.

STUDY METHODS

Clearcuttings can provide a variety of sunlight exposures depending on the size, shape, and orientation of the openings. Narrow strip cuttings appear to offer the best possibilities for practical use (5). With this in mind, a study was designed, first, to test the effect of six different types of strip clearcuttings on the germination, survival, and growth of paper birch and yellow birch; and, second, to obtain detailed records on the light, soil moisture, and soil temperature regimes in these cuttings.

Because of the large variations introduced in field studies by differences in site, soil, animal damage, etc., the experiment was not set up in actual strip cuttings. Instead, the light conditions of various strip cuttings were simulated with shade screens and the entire study was conducted in a ½-acre fenced plot where many miscellaneous factors such as animal damage could be eliminated, other factors such as soil type could be standardized, and still other factors such as soil moisture could be altered as an experimental treatment.

Figure 1. — Aerial view of the study layout, at Bartlett, New Hampshire.

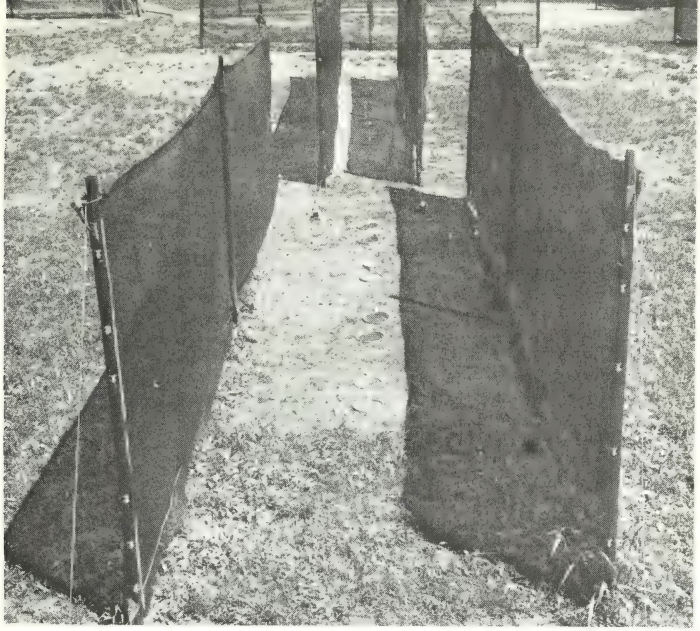


Figure 2. — Close view of two north-south oriented screens. Treatment (b) in foreground, treatment (c) in middle background; and several east-west screens in far background.

The experimental design was a split-plot that contained four blocks, six main plots, and four subplots. Three annual replications were made. The main plots were used for six light-exposure treatments in which open shade, such as that found along the borders of strip cuttings, was created artificially with saran cloth screens. Screens blocking 50 and 80 percent of the light were selected for this study. The 80-percent shade cloth closely simulated the average border shade of strips measured on the Bartlett Experimental Forest in New Hampshire. The screens were 6 feet tall and 20 feet long. A 6-inch gap between the bottom of the screen and the ground allowed air movement along the ground.

Unnatural effects frequently associated with shade screens were minimized with this screen arrangement. There was no overhead screen to intercept rainfall or alter air temperature. Wind movement was slightly restricted, but not so much as by other types of screen. The general arrangement of screens is shown in figure 1 and a close view of several screens is shown in figure 2.

The light exposure treatments were:

Treatment	*Shade cloth*	*Light pattern*	*Type of cutting simulated*
(a)	80%[1]	Full sunlight.	Exposed portions of larger patch, strip, or clearcuttings.
(b)	80%	3½ hrs. sunlight at noon; shade morning and afternoon.	North-south oriented strip with width equal to border-tree height.
(c)	80%	2 hrs. sunlight at noon; shade morning and afternoon.	North-south strip with width equal to ½ border-tree height.
(d)	80%	Sunlight early morning and late afternoon; shade during midday.	East-west strip with width equal to ½ border-tree height.
(e)	50%	Same as (d).	Same as (d) but less dense border shade or shade in a shelterwood cut.
(f)	80%	Direct sun in morning; shade afternoon.	Northwest-southeast strip with width equal to ¾ border-tree height.

[1] An east-west screen was used on the north side of the plots in this treatment; it cast no shade on the plots but helped to keep other factors such as wind movement uniform over all treatments.

There were four subplots at each screen: one for each combination of two species — paper birch and yellow birch — and two moisture regimes. Moisture regime A represented natural soil moisture as affected by light exposure, rainfall, and other environmental factors. Moisture regime B was supplemented so that soil moisture was maintained between 80 and 100 percent of field capacity.

Each subplot consisted of two 6-inch diameter porous clay flower pots, buried in the ground so that the top of the pot was just above the ground line. Moisture regime B pots were nested inside 7-inch plastic pots that had side drain holes 2 inches up from the bottom. A 2-inch level of water was maintained in each plastic pot to serve as a reservoir for the soil in the clay pot. This maintained soil moisture near the field capacity at all times on moisture regime B.

Soil in each pot was obtained from the B_2 horizon of a Hermon sandy loam on the Bartlett Experimental Forest. This soil is typical of those on which birch grows naturally. For the experiment, the soil was dried and thoroughly mixed; stones were removed by passing soil through ¼-inch mesh sieve; then the soil was supplemented with 0.8 g. of 10-10-10 fertilizer and 2.4 g. of lime to every kilogram of soil. Even after these additions, soil nutrient and pH level was low, as evidenced in the following soil analysis performed by the Morgan method (*2*):

pH	*Nitrate nitrogen*	*Ammonia nitrogen*	*Phosphorus*	*Magnesium*	*Potassium*	*Calcium*
5.1	20 ppm (low)	30 ppm (medium)	trace (trace)	1 ppm (very low)	70-90 ppm (low)	520 ppm (very low)

The soil was compacted slightly in the pots to obtain a bulk density of about 1.0.

Birch seed, collected from a single tree of each species and sieved to obtain uniformity of size, was sown at the rate of 200 seeds per pot. As the seeds germinated, they were marked with plastic toothpicks. If a seedling died, its toothpick was removed. Germination and mortality observations were made at weekly intervals. After the main surge of germination was completed, seedlings were thinned to a maximum of nine seedlings per pot to insure that competition did not affect treatment responses. Mortality was therefore a calculated estimate derived from the number of seedlings that died before thinning, the number alive before thinning, and the mortality percentage after thinning.

A duplicate set of two pots was used for height and dry-weight determinations. Seedlings in these pots were started from seed and grown for two months under artificial lights in the laboratory. Each pot that contained two established seedlings was placed under the screens in the study area during the last week of May. Some variation in growth occurred under the artificial lights. Therefore pots were assigned to blocks on the basis of their original height: tallest seedlings in block I, next tallest in block II, and so on. This technique of starting the seedlings early in the laboratory was used because many seedlings that were started from seed in the study area did not make sufficient growth in the first growing sea-

son for accurate growth measurements. Dry-weight measurements do not include leaves. A typical subplot is shown in figure 3.

One pot of each subplot in blocks I and IV was selected for soil-temperature measurements. Copper-constantan thermocouples placed at the surface and 1 inch below the surface were used to measure soil temperature, and Coleman fiberglas soil-moisture units were placed on edge in the top 1 inch of soil to measure moisture. Lead wires from all sensing units were run to rotary switches at a central control panel so that all 96 temperature units and 48 moisture units could be read in quick succession. Coleman units were laboratory-calibrated against gravimetric determinations, using the study soil. Field capacity (0.06 atm) and wilting points (15 atm), as determined on a tension table and pressure membrane, were 48 and 9 percent by volume respectively.

Moisture and temperature were recorded three times a week, May through September, with readings at noon and 3 p.m. EST. On an average of 1 day each week, the readings were taken every hour from 9 a.m. to 3 p.m., and on several occasions readings were taken at hourly and half-hourly intervals from sunrise to sunset. Rainfall and air temperatures were recorded daily at the Bartlett Experimental Forest Headquarters, 1/4 mile from the study area.

Light was measured on each plot an average of once a month. Cumulative light over the middle 8 hours (8 a.m. to 4 p.m. EST) was measured with the chemical light meter (*3*). Intensity readings at 10-minute intervals were also taken on each plot on several occasions with a Weston model-756 illumination meter. Light readings were normally taken on bright sunny days, but one overcast day was sampled for comparison.

The entire study was repeated three times during the growing seasons of 1962, 1963, and 1964. Thus, with 4 blocks, 6 light treatments, 4 species-moisture treatments, and 3 years, 288 plots were used in the study.

Differences due to treatment were tested for significance by analysis of variance. The germination and survival data were subjected to the arc-sin transformation before statistical analysis. A probability level of 0.05 was accepted for significance.

During the course of the study, some changes in procedures were

Figure 3. — A subplot of four pots. The two pots on the left contain large yellow birch seedlings used for growth determinations (moisture regime A pots). The two pots on the right contain paper birch seedlings used for germination and mortality, soil moisture, and temperature measurements (moisture regime B). In the actual study each subplot contained only one species and one moisture regime.

made. For the 1962 and 1963 replications, seed was sown in the pots used for germination during October of the previous year so that it would overwinter in the natural conditions. But some loss of seed was suspected from this procedure. Therefore in 1964 seeds were sown in the spring to minimize such losses.

In 1962, growth determinations were made on seedlings started in the study area. However, because many of these 1962 seedlings did not grow enough to be measured accurately, the seedlings used for growth determinations in 1963 and 1964 were started in the laboratory in a separate set of pots, as previously mentioned. The 1962 growth data have been omitted entirely from this report.

A third major change was in light treatment (f), which was added after the 1962 replication. Thus there are no treatment (f) data for 1962. Neutral values were computed for these missing data, using Snedecor's (6) techniques so that the statistical analysis might be run on all 3 years combined. These neutral values minimize the error sums of squares in the analysis and have a minimum effect on the outcome of the test.

THE ENVIRONMENTS STUDIED

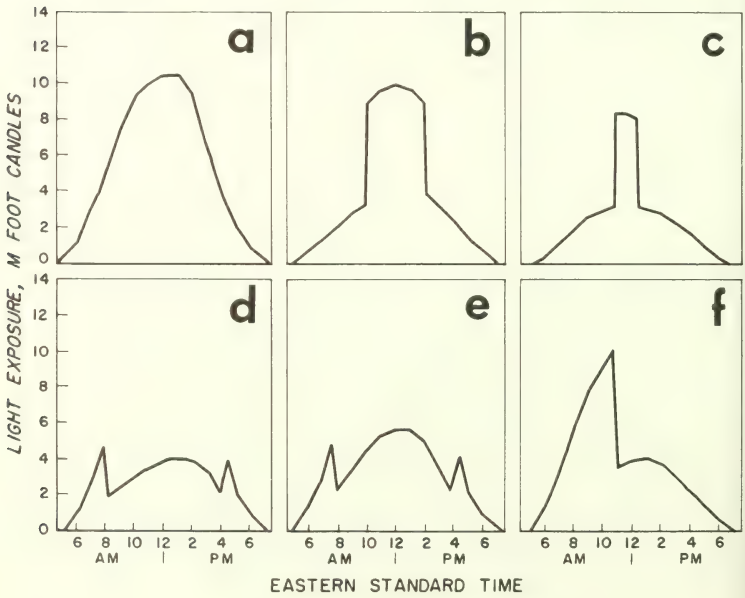
Light Exposure

The actual pattern and intensity of light received under each of the six treatments on a sunny day with intermittent clouds is shown in figure 4. Total or cumulative light received over an entire day is shown as a percentage of full sunlight in the following tabulation. This cumulative light is based on the average of all chemical light readings, and it is adjusted to represent a full 15-hour day.

Light treatment (per cent)					
(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*
100	65	43	48	58	66

The intensity of light received on the overcast day was only about 20 percent of that received on sunny days. On the overcast day, all treatments received about equal light except for treatment

Figure 4. — Light exposure under the various screens on July 28, 1964.



(c), which received 40 percent less than the others because of the closeness of the two parallel screens.

Soil Moisture

Average soil moisture during the 3-year period varied significantly between light treatments and moisture treatments. Most of the variation among light treatments was due to treatment (a) — full sunlight — which had significantly lower moisture than all other treatments combined. Summary of average soil moisture, May to September, for all three growing seasons, is shown in the following tabulation, in percentage by volume.

Moisture regime	*Light treatment*					
	(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*
A	21	30	29	26	26	23
B	45	48	49	48	47	48

Several selected examples of seasonal soil moisture are shown in figures 5 and 6. Figure 5 compares the widely fluctuating natural

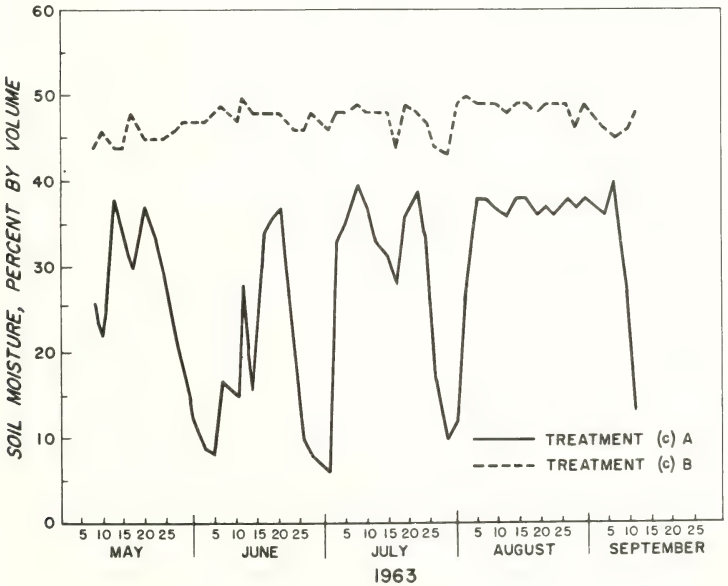
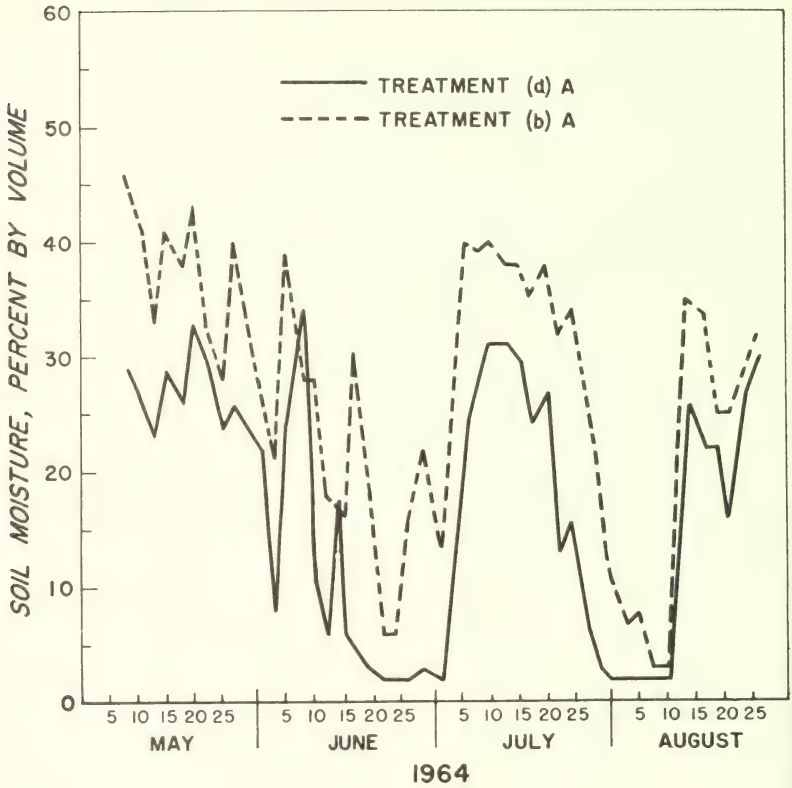


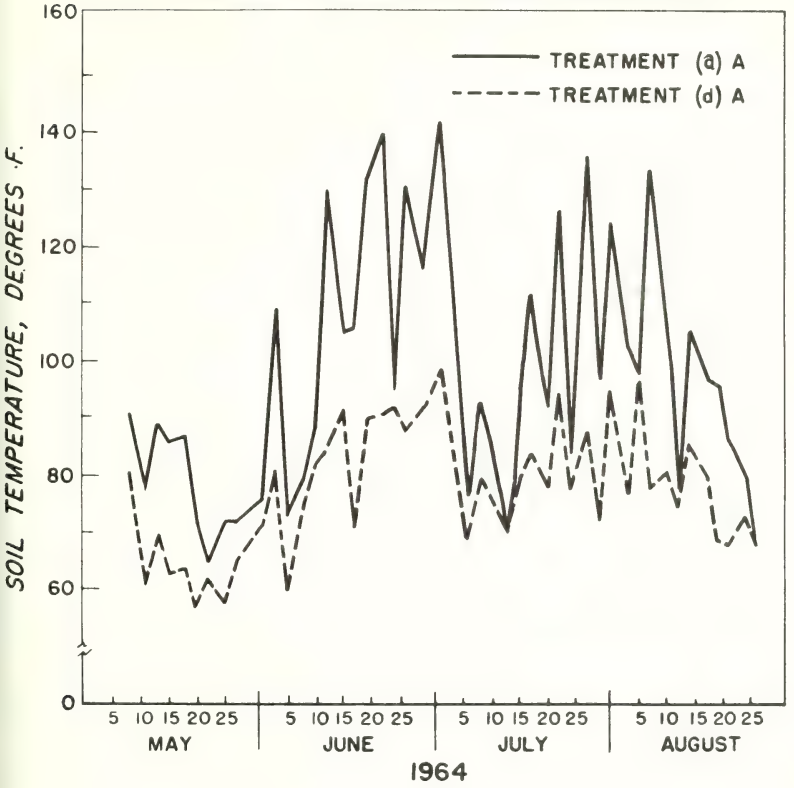
Figure 5. — Soil moisture on narrow north-south treatment (c) during 1963 — moisture regime A compared with moisture regime B.

Figure 6. — Soil moisture on moisture regime A (natural moisture) during 1964. Full sunlight treatment (a) compared with north-south shaded treatment (b).



soil moisture (regime A) on treatment (c) with the higher and relatively stable moisture of regime B on the same treatment. Figure 6 compares seasonal soil moisture on regime A for light treatments (a) and (b). In addition to the fact that moisture content was generally higher on the shaded treatment (b) than on full sunlight treatment (a), it is important to note the differences between the two treatments in regard to the wilting point (9 percent). Treatment (a) fell below the wilting point four times in 1964, for a total of 39 days. Treatment (b) fell below the wilting point only twice, for a total of 13 days. On both occasions when treatment (b) fell below the wilting point, it required 6 or 7 days longer to do so than treatment (a). Thus in a period of long-con-

Figure 7. — Soil temperature on moisture regime A (natural moisture) during 1964. Full sunlight treatment (a) compared with east-west shaded treatment (d).



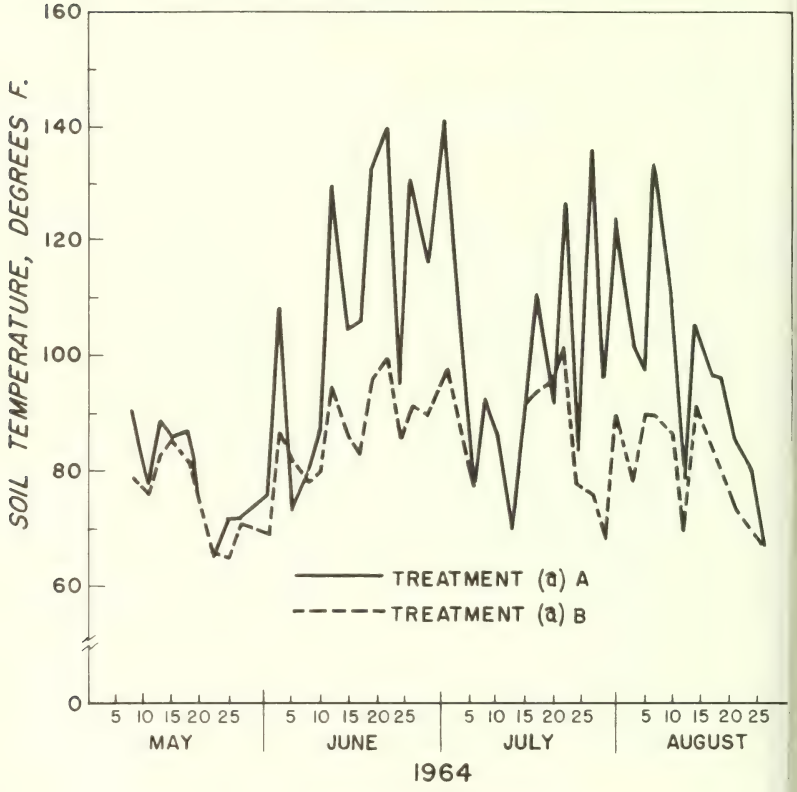
tinued drought the shaded strip offered nearly a week of protection from critically low soil moisture.

Soil Temperature

Average noontime surface soil temperatures, May to September, for all three growing seasons, varied significantly between both light treatments and moisture treatments, as the following tabulation indicates:

Moisture regime	*Light treatment*					
	(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*
A	93°F.	86°F.	81°F.	74°F.	77°F.	76°F.
B	83	81	76	70	74	72

Figure 8. — Soil temperature on full sunlight treatment (a) during 1964. Moisture regime A compared with moisture regime B.



Temperatures were highest in direct sunlight, lowest on plots that received the most shade. The difference in average noontime surface soil temperatures on treatments (a) and (d) was 19°F. Soil temperatures were lower when the soils were moist than when they were dry. In full sunlight, noontime surface soil temperatures averaged 10°F. cooler on regime B than on regime A. However, the magnitude of even these differences is misleading because rainy and overcast days as well as sunny ones were included. On clear days, the differences were much greater. This is evident in a comparison of noontime surface soil temperatures on two light treatments and two moisture regimes respectively (figures 7 and 8). In both cases, differences in excess of 40°F. occurred. Diurnal

fluctuations in soil temperature were closely associated with light exposure; highest temperatures occurred during periods of highest light intensity.

SEEDLING RESPONSES

Germination

Germination for all 3 years combined is shown in table 1. Germination differences among species, light treatments, moisture regimes, and the light-moisture interaction were all highly significant. The differences between species resulted from lower viability of yellow birch seed as revealed in laboratory germination tests. This difference was consistent in each of the 3 years of the study, suggesting that yellow birch seed may normally be less viable than paper birch seed. The other germination differences seem to be straightforward responses to the various environments.

Germination was highest on those treatments that received the most shade, had the highest soil moisture, and did not attain high surface soil temperatures. The interaction of moisture and light is particularly revealing. On treatment (a), where plots were hot and dry from exposure to direct sunlight, the addition of water on regime B increased germination 14 times. But on treatment (c), where heavy shade conserved natural moisture, supplemental watering increased germination only 1.7 times.

On the basis of their ability to provide suitable environments for germination (assuming natural moisture), the six simulated strip cuttings might be divided into three groups: Best conditions

Table 1. — Germination in percent of seeds sown

Species	Moisture regime	Light treatment (a)	(b)	(c)	(d)	(e)	(f)	All light treatments
ıper birch	A	2	9	12	9	7	3	7
ellow birch	A	1	5	10	7	4	3	5
ıper birch	B	20	22	24	18	18	19	20
ellow birch	B	15	16	14	16	14	16	15
Both species	A	1	7	11	8	6	3	6
Both species	B	18	19	19	17	16	18	18

found in a narrow north-south strip (treatment c); intermediate conditions found in treatments (d), (b), and (e) in that order, representing narrow east-west strips and a wider north-south strip; poorest conditions found in treatments (f) and (a), which represented northwest-southeast strips and larger clearcuttings respectively.

Mortality

Differences in mortality (table 2) due to light treatments and moisture regimes were highly significant; those due to the light-moisture interaction were significant at the 0.05 level. Differences between species were not significant. Mortality, like germination, followed a pattern directly related to the environmental treatments. Mortality was lowest on treatments that received heavy shade and supplemental moisture. The light-moisture interaction on mortality, although significant, was not so dramatic as the light-moisture effect on germination. Supplemented moisture reduced mortality 2 times on treatment (a) as compared with 1.3 times on treatment (c).

On the basis of their ability to provide suitable environments for survival (assuming natural moisture), the six simulated strip cuttings might be divided as follows: least mortality in treatments (c), (d), and (e), medium conditions in (b) and (f), and highest mortality in (a).

In general, then, treatments favorable for germination were also favorable for survival. However, there were some slight shifts in the relative favorability, as evidenced by the groupings above. Al-

Table 2. — Mortality in percent

Species	Moisture regime	Light treatment (a)	(b)	(c)	(d)	(e)	(f)	All ligh treatmen
Paper birch	A	73	60	40	44	51	64	55
Yellow birch	A	79	63	53	49	50	57	58
Paper birch	B	44	36	32	27	38	28	34
Yellow birch	B	33	42	40	23	32	35	34
Both species	A	76	61	47	47	50	60	57
Both species	B	38	39	36	25	35	31	34

though these differences are small and are probably of little practical importance, it is interesting to speculate on the reasons.

The north-south screens received direct sunlight for a short period at noon; soil temperatures rise sharply during this period but the duration of exposure apparently does not permit excessive soil drying. The east-west treatments did not receive direct sun during midday; and soil temperatures remained much lower there, while soil moisture was about the same as the north-south treatments. The north-south screens were relatively more favorable for germination than for survival. The opposite was true on the east-west treatments. It would seem, therefore, that the higher soil temperatures and short sunlight exposure on the north-south treatments favored germination of the seed but resulted in some heat damage to the new seedlings.

Height Growth and Dry Weight

Height growth (difference between seedlings at the time they were placed in study and at the end of growing season) and dry weight (total) data are shown in tables 3 and 4.

Two factors limit interpretations of these growth data. First, there was a great deal of unexplained variation, in spite of efforts to reduce it. Even under uniform laboratory conditions, growth differences of 2 or 3 times occurred. These variations probably obscured some relationships that might otherwise have been revealed. The large variations may be characteristic of first-year seedlings. Such variations would likely be less during later years after the seedlings became better established.

Second, the method of watering on moisture regime B, which worked very well for germination and mortality responses, disrupted the normal root growth on regime B seedlings. The 2-inch layer of saturated soil in the pot effectively limited rooting to the upper 2/3 of the soil volume. In contrast, seedlings on moisture regime A were able to utilize all the soil in the pot and many seedlings even extended roots through the hole in the pot bottom into the surrounding soil. Thus lower growth on moisture regime B is probably due to the watering method and not to higher moisture in the usable soil.

Table 3. — Average height growth/seedling in inches

Species	Moisture regime	Light treatment (a)	(b)	(c)	(d)	(e)	(f)	All light treatment
Paper birch	A	1.00	2.00	1.67	2.19	1.66	1.67	1.70
Yellow birch	A	.77	1.98	1.83	1.57	1.75	.84	1.46
Paper birch	B	1.57	1.52	1.40	.89	1.10	1.30	1.30
Yellow birch	B	1.78	1.38	1.55	1.61	1.42	1.14	1.48
Both species	A	.88	1.99	1.75	1.88	1.76	1.26	1.58
Both species	B	1.68	1.45	1.48	1.25	1.26	1.22	1.39

Table 4. — Total dry weight in milligrams/seedling

Species	Moisture regime	Light treatment (a)	(b)	(c)	(d)	(e)	(f)	All ligh treatmen
Paper birch	A	640	991	1,022	1,376	954	811	966
Yellow birch	A	648	1,039	1,236	1,050	848	700	920
Paper birch	B	1,236	815	984	489	681	689	816
Yellow birch	B	932	759	800	996	958	676	854
Both species	A	644	1,015	1,129	1,213	901	756	943
Both species	B	1,084	787	892	742	820	682	834

In spite of these limitations, there are significant and meaningful differences between treatments. On moisture regime A, full sunlight treatment (a) had significantly less growth than the other five treatments. On moisture regime B, differences did not attain significance, but the trend was opposite; that is, greatest growth occurred on treatment (a). Thus height growth was limited by lack of soil moisture under full sunlight conditions with natural moisture, but when soil moisture was not limiting, growth was at least equal, and possibly better, under full sunlight than under shade.

Growth did not vary significantly among the five shaded treatments. However, it must be remembered that the variation in total light received was small, ranging only from 43 to 66 percent of full sunlight. The pattern in which this light was received did vary among treatments, but this apparently had little effect on growth.

Root-shoot ratios, based on dry weight, differed significantly on moisture regime B, where soil moisture was similar on all treatments. Paper birch had a significantly higher root-shoot ratio than yellow birch. Paper birch attained significantly greater root-shoot ratios in full sunlight than in any of the shaded treatments. Yellow birch, the more tolerant of the two species, followed the same pattern, but differences in root-shoot ratios between sun and shade did not attain statistical significance.

These differences in root-shoot ratios may be very important in determining the ecological positions of the two species. Under full sunlight, paper birch has larger roots than yellow birth. Once established, it would thus be better able to survive and grow on dry, fully exposed areas than yellow birch. But when shaded, paper birch root growth is significantly reduced, making it less able to compete there than yellow birch, the root growth of which is not so much affected by moderate shade.

On moisture regime A, soil moisture variations apparently obscured differences in root-shoot ratios. The root-shoot ratios for moisture regime B are given in the following tabulation:

Species	*Light treatment*						*All light treatments*
	(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	
Paper birch	9.94	3.00	4.33	3.97	3.30	3.83	4.73
Yellow birch	6.18	3.02	3.06	4.80	2.99	3.04	3.85

CONCLUSIONS

Because shade favored seedling establishment and full sunlight favored seedling growth, a primary objective of this study was to determine which type of strip might be the best compromise; that is, which would provide both enough shade for seedling establishment and enough direct sunlight for adequate growth.

From the results, it would seem that such a compromise is not really necessary. Differences in growth did occur between the shade treatments and full sunlight treatment, but no significant differences were found among the various shade treatments in this study. Therefore a logical choice would be to use strips that give

the best germination and survival. This would be either a narrow north-south strip (treatment c) or a narrow east-west strip (treatment d), the width being more important than the orientation.

Narrow strips would certainly seem to be the desirable choice if the strips were cut in a progressive series; that is, if the new strips were cut adjacent to old ones at about 3-year intervals, which would remove the shade after an initial establishment period. If strips were not to be cut progressively, or if the cutting intervals were to be much longer than 3 to 5 years, the heavy shade would probably begin to influence seedling growth. In such cases, wider strips — such as treatment b — would be the safer choice.

■

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Costs & Returns

for hardwood lumber production in the Appalachian Region of Kentucky and Ohio

by James C. Whittaker
and Orris D. McCauley

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Costs & Returns

for hardwood lumber production in the Appalachian Region of Kentucky and Ohio

STUDIES made at seven circular sawmills in the Appalachian region of Kentucky and Ohio (fig. 1) show that costs and returns differ among mills because of three major factors: (1) the types of markets for which lumber is produced, (2) the volume sawed annually, and (3) the amount of processing and seasoning done to lumber produced. Classifying sawmills according to these three factors, and examining their annual costs and returns, revealed needed areas of cost control. In addition, comparison of similar costs and returns between mill types indicates what might happen if a small millowner gradually increased production and diversified his operation.

Because knowledge of costs is necessary for controlling them, annual costs and returns were studied at the seven mills, each of which produced ½ million board feet or more annually. Mills of this size class make up 36 percent of the 360 commercial sawmills

Figure 1. — The Appalachian region of Kentucky and Ohio.

and account for about three-fourths of all lumber produced in the region.[1]

Mills selected for study were those that (1) use a circular headsaw for primary log breakdown; (2) have good records of costs, returns, and production; and (3) typify the types of larger scale operations in the study area.

This report summarizes 1 year's costs and returns at each study mill. Operating costs are first considered — what these costs are, and where within the firm they occur. Second, costs are analyzed by volume of lumber and manufactured products containing lumber sold. Finally returns, also analyzed by volume sold, are related to costs to determine net income available for profit and risk.

[1] Sources: Ohio Forestry Association, OHIO FOREST INDUSTRIES DIRECTORY, 1964; and unpublished data of the U. S. Forest Service Central States Forest Experiment Station.

The Study Mills

Two of the seven study mills were classed as small lumber mills. Each produced ½ to 1½ million board feet of lumber annually and sold more than half its production by hardwood lumber grades (fig. 2).

Three study mills were classed as large lumber mills. Each produced more than 1½ million board feet of lumber annually and sold more than half of it by hardwood lumber grades.

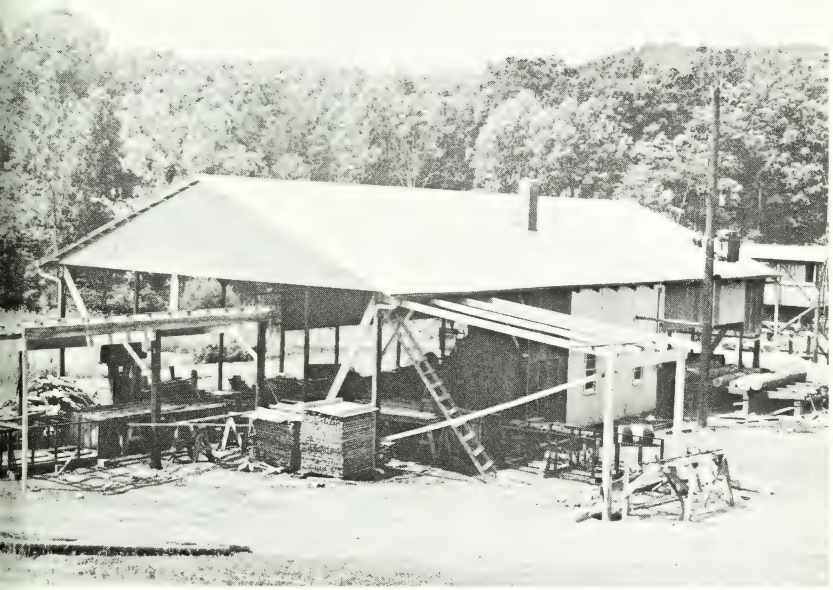

Figure 2. — A typical sawmill of the region.

The two remaining study mills were classed as pallet mills. Each produced 1 million or more board feet of lumber annually and sold more than half of it as pallets or as material for use in pallet manufacture.

Cost Classification

Sawmill operating costs may be divided into two types: fixed and variable. Fixed or overhead costs include such specific expenses as depreciation, insurance, rents, leases, taxes, and interest. They are called fixed costs because their total amount does not change with the volume of lumber produced in any period of time. Therefore they do not directly affect short-term operating decisions such as size of labor force to hire, volume of raw materials to purchase, and types of products to saw. But they must be considered to measure short-term profitability and will therefore be included in all operating costs presented in this paper.

Variable costs are the direct expenses for operating a sawmill. They tend to vary directly with volume of logs purchased and lumber produced. They include such expenses as labor, repairs, maintenance, gasoline, diesel fuel, oil, grease, electricity, sawlogs, and other supplies. Unlike fixed costs, they affect short-term operating decisions because they usually increase or decrease directly with changes in the volume produced.

Results

Types of Costs

Total fixed costs and total variable costs, as a share of all costs, differed little among mill classes (table 1). Moreover, there were no apparent differences in specific fixed costs. But some specific variable costs differed noticeably among the three mill classes.

An individual sawmill operator is cautioned against comparing his own costs with any but the mill class most similar to his own operation. For example, a pallet-mill operator should not compare his labor cost with that of a large-lumber-mill operator and conclude that he can decrease labor cost at his mill from 29 to 19 percent of total expenditures. Labor accounted for a greater share of all costs at pallet mills than at the other types because more labor than machines and materials is needed to manufacture pallets. Likewise, the small-lumber-mill operator should not think he pays more for sawlogs than a large-lumber- or pallet-mill operator. Other expenses, such as office operation, administration, and prod-

Table 1. — Percentage distribution of total costs, by type of mill

Costs	Mill class		
	Small sawmills	Large sawmills	Pallet mills
Fixed:			
Depreciation	4	4	4
Insurance	2	2	2
Rents and leases	—	1	—
Taxes	.5	1	1
Interest	.5	1	1
Total fixed costs	7	9	8
Variable:			
Labor	17	19	29
Repair and maintenance	1	2	3
Fuels and lubricants	1	1	1
Utilities	1	1	2
Sawlogs	65	26	37
Office, overhead, and products shipping	7	17	18
Lumber purchased for resale	([1])	25	—
Other	1	—	2
Total variable costs	93	91	92
Total fixed and variable costs	100	100	100

[1] Less than 0.5 percent.

ucts shipping, played a less prominent role at small lumber mills so sawlog costs constituted a higher portion of all costs at these mills.

Lumber purchased for resale at large lumber mills represented one-fourth of all costs, underlining the importance of wholesaling at such mills. Large mills typically have a large lumberyard and employ one or more lumber inspectors to grade lumber purchased from nearby smaller mills. In some cases, large lumber mills send trucks to pick up this purchased lumber.

Where Costs Are Incurred

Costs incurred at each sawmill were grouped into one of four major activities: (1) sawmill operation, (2) yard operation, (3) administration and marketing, and (4) secondary manufacturing.

Sawmill operations include those jobs performed from the time sawlogs are placed on the log deck to the time lumber is ready for stacking or further processing.

Yard operations include receiving and handling sawlogs and handling and stacking lumber purchased for resale and received from the sawmill.

Administration and marketing include such things as sawlog purchases, wholesale lumber buying, recordkeeping, advertising, supervision, and all costs associated with products shipment.

Secondary manufacturing operations, although not present at every mill studied, include further processing rough-green or air-dry lumber into such products as pallets, skids, boxes, or prefabricated structures.

The share of total costs incurred for sawmilling was about equal for the three mill types (fig. 3). Yard operating and administra-

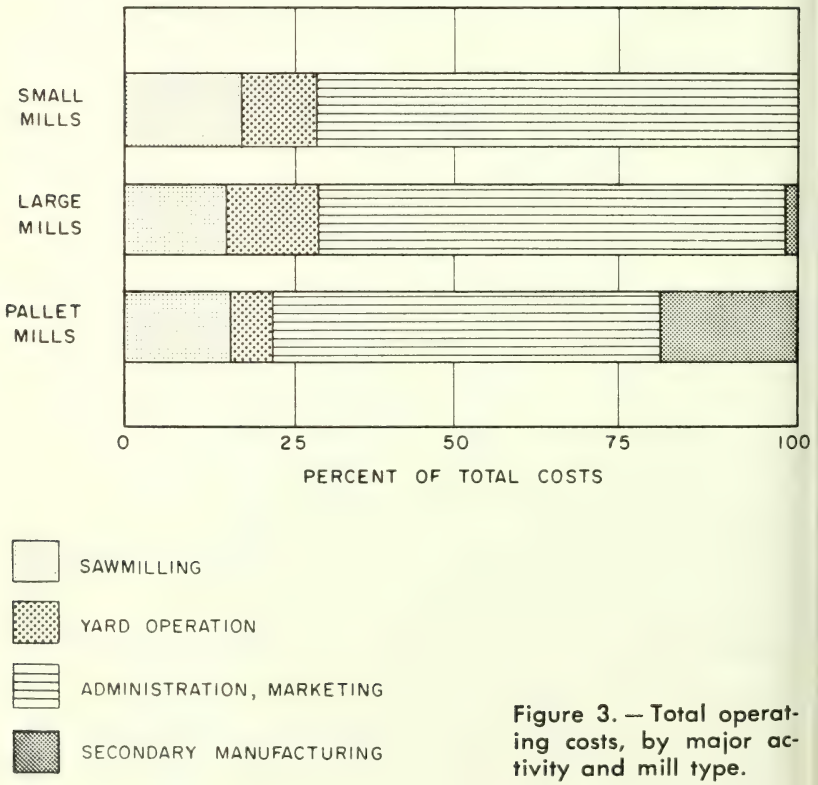

Figure 3. — Total operating costs, by major activity and mill type.

tion and marketing costs represented about the same proportion of total costs at the small lumber and large lumber mills. However, both yard operating and administration and marketing costs occupied a smaller proportion of total costs at pallet mills. This was mainly because pallet and other product-manufacturing costs comprised about 20 percent of their total costs, compared to less than 1 percent at other mills.

Unit Costs

To compare total operating costs for each major activity among the study mills, costs were determined per thousand board feet of lumber sold, either as lumber or in manufactured products. With costs standardized in this manner, three differences became apparent for the mill types studied: (1) sawmilling costs for pallet mills were about $5.50 per thousand higher than for small or large lumber mills; (2) yard operating costs were about $5.00 per thousand higher for large lumber mills than for the other two types; and (3) administration and marketing costs tended to increase with increases in output and the amount of processing (table 2).

Sawmilling costs were higher at pallet mills because such mills generally processed smaller logs and produced mostly 4/4 lumber

Table 2. — Costs per thousand board feet of lumber sold by the study mills[1]

Business activity	Mill class		
	Small sawmills	Large sawmills	Pallet mills
Sawmilling	$12.91	$12.70	$ 18.35
Yard operations	6.90	11.62	6.23
Administrative and marketing activities	54.26	64.26	68.69
Subtotal	74.07	88.58	93.27
Secondary manufacturing	—	.56	25.84
Total	$74.07	$89.14	$119.11

[1]Lumber used in pallet manufacture was included in the volume used to determine board-foot costs.

rather than thicker boards. Both practices tended to increase sawing costs per thousand.

Yard operating costs at large lumber mills probably exceeded those at the other mills because each thousand board feet of lumber sold by a large mill spends more time in the yard and is handled more often than it would be at either a small lumber mill or a pallet mill. At large mills, more rough lumber is air-dried and returned to the mill for resawing and surfacing than at the other types of mills.

Administration and marketing costs tended to be greater per thousand board feet at large mills and pallet mills because: (1) larger office staffs were used; (2) more marketing services were provided (grade-sorting lumber, banding and covering lumber packages, stenciling buyers' names on pallets, and giving discounts for prompt payment of accounts); (3) more supervision was used; and (4) larger depreciation costs were incurred for processing and distributing equipment (especially trucks to move products to markets).

Returns

Gross receipts per thousand board feet of products sold ranged from $79.86 at small lumber mills to $136.54 at pallet mills — a difference of $56.68 (table 3). As volume sold and processing increased, gross receipts per thousand board feet increased both for all products combined and for specific products. Though increased processing probably contributed much to the higher gross receipts at large lumber mills and pallet mills, ability to supply greater volume must have also been important. Generally, when two or more types of mills marketed the same product, the higher gross receipts per thousand board feet went to the type supplying the greater volume.

Although each mill tended to concentrate on sawing one specific product (for example, graded lumber), most mills supplemented production with several other products. Consequently, the average return from all products for any type of mill was influenced by the return on each product sold. This was most evident at pallet mills where the return on all products per thousand board feet

Table 3. — Gross receipts per thousand board feet of lumber by type of product and mill type

Type of product	Mill type		
	Small sawmills	Large sawmills	Pallet mills
Graded lumber	$80.25	$106.09	$ 90.57
Flooring	—	74.13	—
Construction and local-use lumber	61.36	81.56	58.71
Pallets, boxing, crating, and blocking	65.00	73.99	131.11
Ties and timbers	—	81.76	139.07[1]
Miscellaneous products[2]	90.20	109.96	163.72
All products (weighted average)	$79.86	$ 97.02	$136.54

[1] Includes special orders of large timbers.
[2] Includes veneer logs, cooperage logs, fenceposts, retail sales, and stacking sticks.

exceeded the return on pallets, boxing, crating, and blocking.

Subtracting average total cost (table 2) from the all-products average return (table 3) gives a net income before taxes (return to management, plus margin for risk) of $5.79, $7.88, and $17.43 per thousand board feet at small lumber, large lumber, and pallet mills, respectively. These amounts approximate 7 percent, 8 percent, and 13 percent of their respective weighted average prices.

Conclusions

We believe the sawmill operations studied typify those in the Appalachian region of Kentucky and Ohio. To the extent that they do, costs, returns, and net incomes at other sawmills in the region may approximate those reported for the study mills.

Small-lumber-mill operators, for example, may expect sawlog expenditures to account for almost two-thirds of their total annual costs. They may also expect each major activity at their firm to contribute approximately the same share to total annual costs as those observed at the study mills. Likewise, large-lumber-mill and pallet-mill operators may expect their expenditures for major activities to comprise nearly the same shares of total costs as those observed at the study mills.

Although all operating costs are important, this study, by identifying the largest costs, may have identified the costs that deserve the most managerial attention. Among fixed costs, for example, mill managers should closely examine depreciation and insurance costs before spending much time on others. The greatest variable costs are for stumpage and sawlogs, purchase of lumber for resale, labor and office operation, products distribution, and administration. These large costs are the ones that managerial cost-control efforts are most likely to reduce significantly. They should therefore be considered first when trying to increase operating profits.

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Air-Drying Practices In The Central Appalachians

An evaluation of commercial sawmill operations, with some recommendations for improvements to reduce lumber losses

by Donald G. Cuppett

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Air-Drying Practices In The Central Appalachians

THE IMPORTANCE OF AIR-DRYING

THE air-drying process is particularly important in the central Appalachian region, where approximately two-thirds of all hardwood lumber produced is marketed air-dried. In a recent study of West Virginia sawmills, it was found that 69 percent of the lumber shipped was air-dried, 8 percent was kiln-dried, and 23 percent was green.[1] These proportions are believed to be typical of the central Appalachian region.

The efficiency of air-drying and the quality of air-dried lumber are important to both lumber producers and users. Poor air-drying practices cause seasoning defects that lower the grade and value of lumber; this degrade results in loss of income to the lumber producers and higher remanufacturing costs to the lumber users. Furthermore, improper air-drying causes large variations in moisture content, which results in excessive kiln-drying costs.

All these effects of poor air-drying create problems in marketing hardwood lumber. Therefore our Forest Products Marketing Laboratory made a study of commercial air-drying practices in

[1]Reid, W. H., W. W. Christensen, and N. D. Jackson. MARKETING LUMBER PRODUCED BY SAWMILLS IN WEST VIRGINIA. W. Va. Agr. Exp. Sta. Interim Rep. on Reg. Res. Proj. NEM-24, Phase I and II, 20 pp., illus., 1962.

the central Appalachian region (1) to evaluate the different drying practices in terms of degrade losses and moisture-content variation of air-dried lumber; and (2) to determine what improvements in drying practices are needed at mills where seasoning degrade losses and moisture-content variation are excessive.

THE STUDY

A stratified random sample, including 18 of the sawmills in West Virginia, Virginia, Kentucky, and Tennessee, was selected for study. Ten of these were small mills that produce ½ to 3 million board feet annually; the other eight were large mills that produce more than 3 million board feet annually. Sawmills in these two classes account for an estimated 90 percent of all lumber produced in the region.

Seasoning degrade was determined by inspecting air-dried lumber in randomly selected shipments at each mill. The grade[2] and volume of each board were determined and recorded on the standard lumber-shipping tally form. An additional record was made for each board that contained seasoning degrade to show the grade with and without seasoning degrade, the air-dry volume of the board, the type of seasoning defect, and the probable cause of defect.

Degrade losses were computed in dollars per thousand board feet by applying the f.o.b. mill prices by grades to the actual air-dry grade and the potential grade of each degraded board. The total value losses for all degraded boards in a shipment, divided by the total volume in the shipment, gave the monetary degrade loss per thousand board feet.

The study was limited to red oak and yellow-poplar in 4/4- and 5/4-inch thicknesses, because these two species and thicknesses account for more than half the hardwood lumber produced in the region. Approximately half of this lumber was dried in the fall and winter, half in the spring and summer. Grades No. 3A Common and Better were included, and the average grade of lumber inspected was slightly better than No. 1 Common. A

[2]National Hardwood Lumber Association grades.

total of 195,838 board feet of red oak and 118,015 board feet of yellow-poplar were inspected at the 18 sample mills (table 1).

For determining moisture content, sample boards were selected from each sample shipment by striking a chalk line diagonally from the upper left to lower right corners of the end of the stacks. Beginning with the top layer, the chalk-marked boards in every other layer were tested with a resistance-type electric mois-

Table 1.—*Number of shipments and volume of lumber inspected at different classes of sawmills, by species and thickness*

(In board feet. Numbers in parentheses show number of shipments)

Sawmill size-class	Red oak			Yellow-poplar		
	4/4	5/4	Total	4/4	5/4	Total
Small	68,619 (8)	34,543 (4)	103,162 (12)	33,799 (3)	19,758 (1)	53,557 (4)
Large	69,257 (3)	23,419 (3)	92,676 (6)	37,934 (3)	26,524 (1)	64,458 (4)
Total	137,876 (11)	57,962 (7)	195,838 (18)	71,733 (6)	46,282 (2)	118,015 (8)

ture meter. Measurements were taken at points in the middle and 1 foot from each end of the boards. The insulated pins were driven to one-third the thickness of the sample board.

Temperature, rainfall, wind speed, and relative humidity data for the study period were collected from U. S. Weather Bureau stations located near the sample mills. To pinpoint extremes that might have unusual effects on drying degrade or moisture-content variation during the study period, these data were compared with the Weather Bureau's normal data.

Descriptive data on yard layout and lumber piling and handling methods were collected for each sawmill lumber yard in order to compare the drying degrade and moisture-content variations that resulted from the different drying practices.

DEGRADE LOSSES IN RED OAK

Volume and Value of Degrade

Of the 195,838 board feet of red oak lumber inspected, 28,982 board feet, or 14.8 percent, were degraded. Degrade losses for red oak averaged $13.95 per thousand board feet, or 9.6 percent of the air-dry lumber value. Losses for individual shipments of red oak ranged from 35 cents per thousand board feet to more than $100 per thousand board feet. A detailed breakdown of degrade losses for red oak by lumber thickness and mill size-class is given in table 2.

Table 2.—*Average air-drying degrade losses for red oak lumber shipments, by lumber thickness and mill size-class*

Sawmill size-class	Average degrade loss per thousand board feet					
	4/4		5/4		Total	
	Dollars	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*
Small	25.73	18.2	6.11	4.1	19.75	12.5
Large	9.90	7.6	2.96	1.9	8.15	5.9
Aver.	17.78	13.1	4.84	3.2	13.95	9.6

Past research has demonstrated that degrade losses from air-drying 4/4 red oak can be limited to less than 2 percent of lumber value.[3] These results are further substantiated by our study: at half the sample mills, average degrade losses for red oak were only 1.2 percent of lumber value; at the other half, average degrade losses for red oak were 18.8 percent of lumber value. Thus the better commercial air-drying practices are probably adequate for achieving acceptable control of drying degrade losses.

[3]Peck, E. C. AIR-DRYING 4/4 RED OAK IN WISCONSIN. Forest Prod. J. 9 (7): 197-203, illus., 1959.

Both large and small mills experienced significantly less average degrade losses in drying 5/4 red oak than 4/4 red oak (table 2). This is contrary to what might be expected, since the higher degrade losses usually occur in drying the thicker lumber. Observations at the sample mills indicated that the mill personnel recognize this and use greater care in piling and roofing the 5/4 lumber than the 4/4 lumber.

Types and Occurrence of Defects

The four types of seasoning degrade considered in the study were checks, splits, warp, and chemical stain. Table 3 shows the number of boards, volume, and percentage of degrade by each type of drying defect for red oak lumber.

Table 3.—*Amount of degrade for red oak lumber, by type of drying defect*

Type of defect	Boards degraded	Volume degraded	Percent of degraded volume	Percent of total volume
	No.	*Bd. ft.*	*Percent*	*Percent*
Checks	1,989	16,505	57.0	8.5
Splits	556	5,477	18.9	2.8
Warp	496	4,394	15.1	2.2
Stain & other	333	2,606	9.0	1.3
Total	3,374	28,982	100.0	14.8

Checks caused more than half the degrade losses in red oak. They occurred mostly in stacks where roofing was not used. They also occurred where the edges of boards were exposed by bunk spaces in unit-packaged piles. More checks occurred in forklift yards than in dock yards: the wider stack spacing and larger alleys in forklift yards cause faster drying, and frequently increase degrade from checking and splitting. Average degrade losses for forklift yards were $20.00 per thousand board feet as compared with $3.49 per thousand board feet for dock yards

(table 4). However, average degrade losses in 4 of 11 red oak shipments from forklift yards were less than $2 per thousand board feet.

Splits were prevalent in stacks that were not roofed. Splits also occurred in stacks where the end-stickers were not flush with the ends of boards, and elsewhere in stacks where board ends were not supported by stickers.

Most warp occurred in stacks where sticker and bunk alignment was poor. Warp also occurred in the top layers of unroofed stacks and between stickers where sticker spacing exceeded 36 inches. Minor amounts of sticker stain occurred where green or wide stickers were used.

Degrade losses for red oak lumber piled in the fall and winter

Table 4.—*Comparative air-drying degrade losses for red oak lumber, by type of yard and mill size-class*

Sawmill size-class	Average degrade loss per thousand board feet			
	Forklift yards		Dock yards	
	Dollars	*Percent*	*Dollars*	*Percent*
Small	42.50	29.3	3.93	2.8
Large	6.50	6.5	.70	.5
Average	20.00	14.2	3.49	2.5

Table 5.—*Air-drying degrade losses for red oak lumber by season of the year*

Season	Average degrade loss per thousand board feet					
	Small sawmills		Large sawmills		All sawmills	
	Dollars	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*
Spring & summer[1]	5.35	4.1	4.53	2.4	5.18	3.7
Fall & winter[2]	35.50	22.3	8.78	6.7	18.78	13.3

[1]April 1 through September 30.
[2]October 1 through March 31.

averaged $18.78 per thousand board feet, or 13.3 percent of lumber value. Losses for lumber piled in the spring and summer averaged $5.18 per thousand board feet, or 3.7 percent of lumber value (table 5). The fall and winter shipments included lumber piled during October, when weather conditions favored checking and splitting. However, degrade losses for that portion of the fall- and winter-piled lumber that had been roofed averaged only $2.79 per thousand board feet, or 2.3 percent of lumber value.

The repeated wetting and drying of uncovered red oak lumber during the fall and winter months increases checking, the chief type of defect in the species. Although the temperatures are normally much colder during this period of the year, there are enough days of warm sunshine, low relative humidity, and high winds to cause damage to unprotected lumber.

DEGRADE LOSSES IN YELLOW-POPLAR

Volume and Value of Degrade

Of the 118,015 board feet of yellow-poplar inspected, only 654 board feet, or 0.6 percent of the volume, were degraded (table 7). Degrade losses averaged 21 cents per thousand board feet or 0.2 percent of lumber value. Losses for individual shipments ranged from zero to 73 cents per thousand board feet.

The relatively low air-drying degrade losses for yellow-poplar as compared with red oak indicate the relative difficulty in drying the two species. Practices that facilitate rapid drying tend to cause checking, which is a major type of degrade in red oak. On the other hand, rapid drying helps to prevent statin, which is the major cause of degrade in yellow-poplar. All of the sample mills used anti-stain treatment on yellow-poplar during the spring and summer months: otherwise the drying practices for yellow-poplar were the same as those for red oak. The air-drying degrade losses for yellow-poplar are shown in table 6.

Causes and Types of Defects

Stain, the principal type of degrade in yellow-poplar, occurred mostly in sections of yards where drying was retarded. And

Table 6.—*Average air-drying degrade losses for yellow-poplar lumber shipments, by lumber thickness and mill size-class*

Sawmill size-class	Average degrade loss per thousand board feet					
	4/4		5/4		Total	
	Dollars	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*
Small	0.16	0.1	0.24	0.2	0.19	0.2
Large	.39	.6	.00	.0	.23	.2
Average	0.28	0.3	0.10	0.1	0.21	0.2

Table 7.—*Amount of degrade for yellow-poplar lumber, by type of drying defect*

Type of defect	Boards degraded	Volume degraded	Percent of degraded volume	Percent of total volume
	No.	*Bd. ft.*	*Percent*	*Percent*
Stain	56	323	49.3	0.3
Checks	24	145	22.2	.1
Warp	6	41	6.3	.1
Splits & other	12	145	22.2	.1
Total	98	654	100.0	0.6

Table 8.—*Comparative air-drying degrade losses for yellow-poplar, by type of yard and mill size-class*

Sawmill size-class	Average degrade loss per thousand board feet			
	Forklift yards		Dock yards	
	Dollars	*Percent*	*Dollars*	*Percent*
Small	0.23	0.2	0.14	0.1
Large	.23	.2	—	—
All sawmills	0.23	0.2	0.14	0.1

Table 9.—*Air-drying degrade losses for yellow poplar, by season of year*

Season	Average degrade loss per thousand board feet					
	Small sawmills		Large sawmills		All sawmills	
	Dollars	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*
Spring & summer	0.23	0.2	0.02	—	0.09	0.1
Fall & winter	.19	.1	.73	0.09	.38	.4

usually it occurred in the lower layers of boards in stacks where ground clearance was less than 1 foot, and in stacks where there was little or no lateral spacing between boards.

Approximately twice as much degrade occurred in the lift-truck yards as in the dock yards (table 8). Degrade losses in yellow-poplar lumber piled in fall and winter were more than four times those of lumber piled in the spring and summer (table 9).

MOISTURE CONTENT OF AIR-DRY MATERIAL

Red Oak

Table 10 shows moisture-content data for 15 of the sample shipments of red oak lumber. The other three shipments of red oak contained some restacked lumber that was unusually dry, so they were not included in the data. Average moisture content in 9 of the 15 shipments was less than 20 percent, in 3 of the shipments from 20 to 23 percent, and in the remaining 3 shipments from 25 to 27 percent.

Moisture-content variation within the individual red oak shipments ranged from 8 to 22 percent. In 8 of 15 shipments it was 11 percent or less, and in 7 other shipments it ranged from 12 to 21 percent. Generally, less variation in moisture content occurred in shipments with low average moisture contents: only 2 of 10 shipments averaging 20 percent or less exceeded 11 per-

Table 10.—*Moisture content data for 15 shipments of red oak lumber*

Sample number	Type of yard	Thickness	Season	Days in stack	Average moisture content	Tota moistu conte variati
		Inches		*Days*	*Percent*	*Perce*
1	Dock	5/4	Year-round	480	13	11
2	Dock	5/4	Fall-winter	182	21	14
3	Dock	5/4	Fall-winter	99	25	12
4	Dock	4/4	Year-round	458	16	12
5	Dock	4/4	Fall-winter	305	16	9
6	Dock	4/4	Fall-winter	184	20	10
7	Dock	4/4	Fall-winter	181	17	11
8	Forklift	5/4	Spring-Summer	41	27	18
9	Forklift	5/4	Fall-winter	152	18	7
10	Forklift	4/4	Spring-summer	120	15	10
11	Forklift	4/4	Spring-summer	108	17	10
12	Forklift	4/4	Spring-summer	86	15	7
13	Forklift	4/4	Fall-winter	118	18	13
14	Forklift	4/4	Fall-winter	111	23	18
15	Forklift	4/4	Fall-winter	110	26	21

Table 11.—*Moisture-content data for 8 shipments of yellow-poplar*

Sample number	Type of yard	Thickness	Season	Days in stack	Average moisture content	Tota moistu conte variati
		Inches		*No.*	*Percent*	*Perce*
1	Forklift	5/4	Fall-winter	67	19	31
2	Forklift	4/4	Fall-winter	135-143	13	10
3	Forklift	4/4	Spring-summer	28	13	16
4	Forklift	4/4	Spring-summer	64	13	10
5	Dock	5/4	Fall-winter	45	16	17
6	Dock	5/4	Fall-winter	33	24	28
7	Dock	4/4	Spring-summer	26	13	17
8	Dock	4/4	Fall-winter	33-48	16	13

cent total variation, whereas all 5 shipments averaging more than 20 percent exceeded 11 percent total variation.

Commercial kiln-drying costs are estimated by the lumber industry at approximately $1.25 per thousand board feet per day. At this rate, the added kiln-drying costs for 4 of the 7 shipments exceeding 11 percent total variation in moisture content would be $1.25 per thousand board feet; and for the other three shipments the added costs would be $2.50 per thousand board feet.

Yellow-Poplar

Table 11 shows a summary of moisture-content data for yellow-poplar. Seven of the 8 shipments of yellow-poplar had average moisture contents of less than 20 percent, and one shipment averaged 24 percent. Moisture-content variation within 2 of 8 individual yellow-poplar shipments was 11 percent or less; in the other 6 shipments it ranged from 13 to 31 percent. The yellow-poplar lumber at or near the equilibrium-moisture-content (EMC) condition had the least total moisture-content variation.

Although there was more total variation in moisture content in yellow-poplar shipments than in red oak shipments, the faster kiln-drying rates for yellow-poplar made this less of an economic factor than for the red oak.

WEATHER CONDITIONS

Weather data were collected for stations near the sample sawmills to see if conditions during the study period varied significantly from normal conditions. Because the most complete data were available for the Charleston, West Virginia, Weather Bureau Station, a thorough evaluation of conditions at this station was made for the calendar year 1963, which included most of the drying period in this study.

From mid-march to early November was found to be the active drying period. During the remainder of the year, temperatures averaged below 50° F. and relative humidity above 65 percent. Although equilibrium-moisture-content under these conditions is often low enough for drying to take place, the temperatures are so low that the drying rate is very slow. While 4/4 red oak in

lift-truck yards dried to an average moisture content of less than 20 percent in 90 days during the spring and summer months, 150 to 180 days were required for this amount of drying during the fall and winter months.

Average Charleston monthly temperatures for 1963 were near normal except for August and September when they were, respectively, 4 and 9 degrees above normal.

Total precipitation for the entire year was 30.53 inches as compared with a normal total of 44.43 inches. Precipitation was below normal for all except 2 months of the year, March and November. April had only 1.21 inches and October 0.09 inches of

Table 12.—*Summary of air-drying practices used at 18 sample mills*

Practices	Sawmill size-class					
	Small sawmills		Large sawmills		All sawmills	
Yard system:	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
Forklift	4	40	6	75	10	5
Dock	6	60	2	25	8	4
Pile foundations:						
Adequate ground clearance	4	40	2	25	6	3
Adequate number of vertical supports	5	50	5	62	10	5
Proper alignment	8	80	6	75	14	3
Stickers and bunks:						
Proper number and spacing	5	50	6	75	11	1
Proper alignment	6	60	5	62	11	1
Proper size and quality	6	60	6	75	12	7
Stack roofs:						
Tight portable	0	0	2	25	2	1
Tight shed	1	10	0	0	1	5
Loose boards	6	60	4	50	10	5
None	3	30	2	25	5	8
Yard layout:						
Proper orientation and spacing	9	90	6	75	15	3
Adequate drainage	5	50	7	87	12	7
Adequate vegetation and debris control	3	30	4	50	7	9
Roads well-constructed of suitable material	6	60	6	75	12	7

precipitation, as compared with normal precipitation of 3.68 inches and 2.58 inches, respectively.

During April the average relative humidity at 1:00 p.m. was 38 percent (10 percent below normal), and during October it was 37 percent (15.5 percent below normal). The number of clear and partly cloudy days for the year was near normal; however, in October there were 29 days in this category as compared with a normal of 19. The resulting solar heating conditions and the low relative humidity during October could cause severe checking and splitting in uncovered red oak lumber. Of the sample red oak lumber included in this study, seven shipments were stacked or were drying during October 1963. Four of these were roofed; they averaged $3.38 per thousand board feet in degrade losses. The other three were not roofed; they averaged $15.50 per thousand board feet in degrade losses.

So, while extreme weather conditions can cause extra degrade, most of the effect of these conditions can probably be controlled by proper air-drying practices.

CURRENT PRACTICES

The air-drying practices used at the 18 sample sawmills are summarized in table 12. Ten of the 18 sample mills used forklift yard systems, and three other sample mills converted to forklift systems while the study was in progress. Unfortunately, much of the potential advantage of forklift trucks in lumber handling is being lost through degrade caused by improper use of the trucks at many sawmills (fig. 1). Forklift systems require more yard space per unit of production, better yard roads and drainage, and better lumber piling than the older dock-type yards.

Generally, the yard orientation and spacing of lumber piles was satisfactory. Twelve of the 18 yards had good roads and drainage, but only 6 had adequate vegetation and debris control. Pile foundations were constructed of adequate materials at all yards, but only 4 vertical supports per foundation were used at 8 of the 18 yards. Ground clearance at 12 of the yards averaged less than 12 inches. Sticker and bunk quality was satisfactory at 12 of the

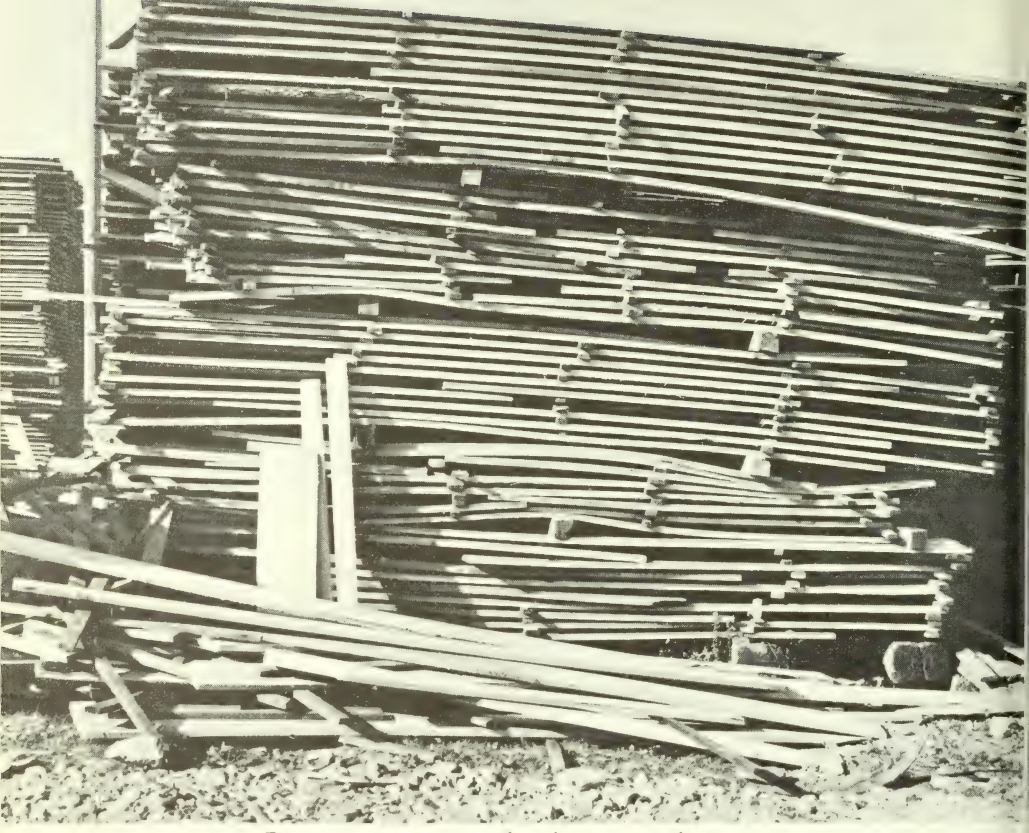

Figure 1.—An example of poor air-drying practices in a forklift-type of drying yard. Much of the lumber in this stack has been degraded by warp, splits, and checks.

yards, and stickers and bunks were properly spaced and aligned at 11 of the yards.

The one major deficiency at most yards was in stack roofing practices. Only 3 of 18 yards used either tight-portable or shed-type stack roofs, and 5 mills used no roofing at all. The loose-boards used for roofs at 10 of the yards did not entirely prevent rain and snow from rewetting the lumber and thus were not so effective as tight-portable or shed roofs. Loose boards are also more expensive to use, because they must be moved by hand labor. However, they are effective as sun shields and are better than no roofing at all.

Most of the improvement needed in air-drying practices could be achieved without significant additional capital expenditures. Rather, better use of existing yard space, materials, and equip-

ment is needed. For example, the 10 mills that use loose boards for roofing lumber stacks could construct tight portable roofs from these boards; the cost of building the roofs would include only labor and nails, which would quickly be offset by savings in degrade losses and handling costs.

SUMMARY

A study of the efficiency of commercial air-drying practices was conducted at 18 randomly selected sawmill lumber yards in the central Appalachian hardwood region. Air-drying degrade losses averaged $13.95 per thousand board feet for red oak, and 21 cents per thousand board feet for yellow-poplar. Degrade losses were within acceptable limits for all sample shipments of yellow-poplar; but losses in half the sample red oak shipments were excessive.

Greater degrade losses occurred at the smaller sawmills than at the larger ones, at forklift-type yards than at dock-type yards, and in fall- and winter-stacked lumber than in spring- and summer-stacked lumber. Less drying degrade occurred in 5/4 lumber than in 4/4 lumber.

The chief types of defects in red oak were checks and splits, and in yellow-poplar, stain and warp. Checks in red oak occurred mostly in stacks where roofing was inadequate, and near the edges of boards adjacent to bunk spaces; splits occurred in unroofed stacks and in stacks where too few stickers were used. Stain in yellow-poplar occurred mostly in the bottom layers of stacks that had inadequate ground clearance.

Variation in moisture content within individual shipments exceeded 11 percent in 7 of 15 shipments of red oak and in 6 of 8 shipments of yellow-poplar. Time of year or type of yard seemed to have little relationship to variation in moisture content in either species. Lumber of both species at or near the equilibrium-moisture-content condition had the least variation in moisture content.

Weather conditions during the study period were near normal except for total annual rainfall, which was 13.9 inches below normal for the year, and for average relative humidity, which

was 10.0 percent and 15.5 percent below normal during April and October respectively. These conditions probably contributed significantly to the degrade in red oak.

RECOMMENDATIONS

Many of the sawmills in the central Appalachian region could increase their *net* income from red oak lumber by $10 or more per thousand board feet by improving their air-drying practices. At the same time they could help make finished wood products more competitive because air-dried lumber that contains minimum degrade and relatively uniform moisture content costs less to kiln-dry and remanufacture (fig. 2).

Special precautions should be taken in drying red oak in forklift yards. The forklift yards are more open than dock yards, and the resulting exposure causes faster drying and more checking and splitting, the chief types of degrade in red oak. The essential practices for air-drying red oak with minimum degrade losses in the central Appalachian region are:

1. Pile foundations should have at least 5 vertical supporting members per 16 feet of length, and the minimum ground clearance should be 12 inches.

2. Lumber should be box-piled or sorted by lengths for drying, and end stickers should be flush with the ends of boards.

3. Stickers should be of uniform thickness, 1½ to 2 inches wide, and should be dried below 20 percent moisture content before use; except for the lower grades of lumber, stickers should be spaced on 24-inch centers.

4. Both stickers and bunks should be aligned vertically over the pile foundation members. Blank spaces in the packages should be blocked with small trim-ends to prevent sticker damage and warped lumber.

5. The No. 3A Common and Better grades should be covered with tight stack-roofs; this should be done immediately after

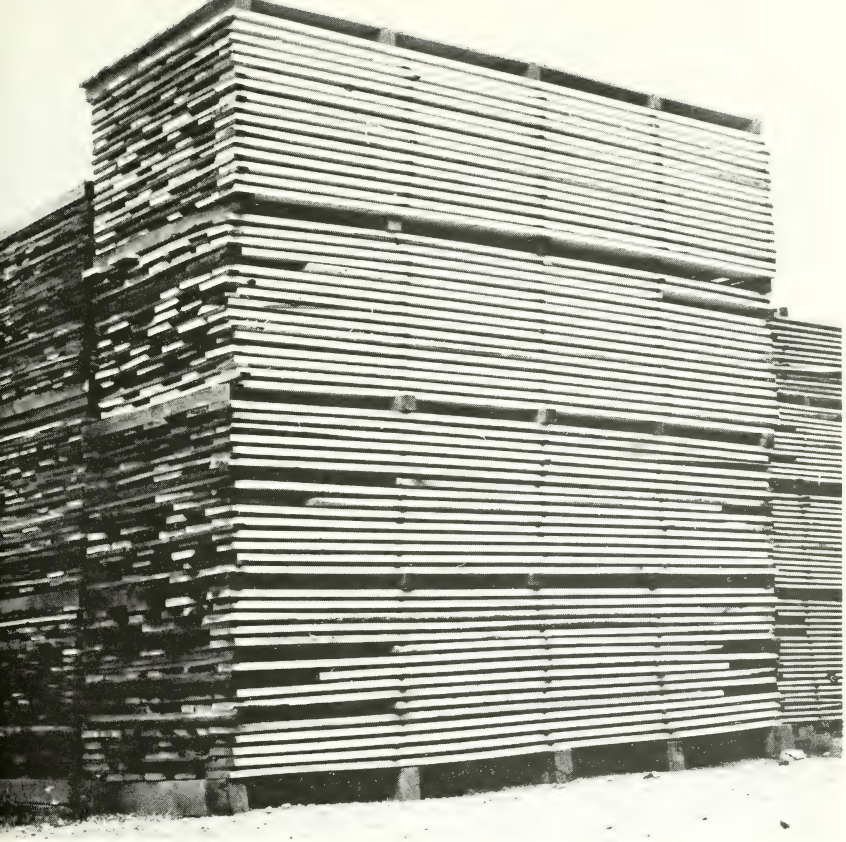

Figure 2.—An example of good air-drying practices in a forklift-type drying yard. Note the sticker and bunk alignment, portable stack-roof, and absence of vegetation or debris around the lumber stack.

the lumber is placed in the yard because serious checking may occur within 24 hours on warm dry days.

6. The yard surface should be kept free of weeds and debris; it should also be well-drained, and alleys should be paved with crushed stone or other suitable material.

7. The No. 1 Common and Better grades should be placed in the more protected areas of the lumberyard. In yards where rapid drying conditions exist, lumber stacks should be oriented with the boards parallel to the prevailing wind. Six and eight-quarter lumber should be end-coated, or the ends of the stacks should be covered with paper or cull boards.

Items 1 to 6 above apply equally to drying yellow-poplar in all thicknesses. However, to prevent stain, yellow-poplar should be placed in those yard areas where rapid drying will take place. In yards where drying is normally slow, the minimum ground clearance for lumber in stacks should be increased to 20 inches or more.

Chemical anti-stain treatment should be used for yellow-poplar from May through September. Several commercial brands are available, and all are effective when used according to the manufacturer's directions. Personnel handling treated lumber should wear long-sleeved shirts, gloves, and goggles (or glasses) because the chemical solutions are irritating to the skin and eyes.

Individual sawmill operators should determine the extent of air-drying degrade in their lumberyards at regular intervals in order to pinpoint the drying practices that need improvement. U. S. Forest Service Research Note NE-32[4] provides instructions for doing this.

[4]Cuppett, D. G. How to determine seasoning degrade losses in sawmill lumber yards. U. S. Forest Serv. Res. Note NE-32, 7 pp., illus., 1965. NE. Forest Exp. Sta., Upper Darby, Pa.

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DEER BROWSING IN NORTHERN HARDWOODS AFTER CLEARCUTTING

effect on height, density, and stocking of regeneration of commercial species

U. S. FOREST SERVICE RESEARCH PAPER NE-57
1967

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

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DEER BROWSING IN NORTHERN HARDWOODS AFTER CLEARCUTTING

Timber & Game

THERE is a close relationship between management of forest land for timber and management for game. This is especially evident in the use of cutting practices that yield both timber and deer browse.

The relationship reaches almost symbiotic proportions in northern hardwoods after clearcutting for stand regeneration. Usually an abundance of woody vegetation — both commercial and noncommercial species — is produced; and much of this can be utilized by deer with no undesirable effect on the composition and growth of the future stand. Under light to moderate browsing, seedlings of commercial species may actually undergo less competition because deer prefer the faster-growing sprouts. And stands of seedling origin are generally thought to be of higher quality than those of sprout origin.

The problem common to both timber management and deer management arises with overbrowsing. In northern hardwoods,

the species most commonly affected are those that are about equally important as sources of both browse and timber: sugar maple, red maple, yellow birch, black cherry, and white ash.

Direct evidence of overbrowsing in these species is a high proportion of browsed twigs, reduced height of stems, and a hedged appearance of seedlings. The low rate of seedling density that often accompanies evidence of overbrowsing, and which is generally presumed to be the result of heavy browsing, is more serious. But this may also be the result of the influence of other factors (poor soil or poor drainage, or plant competition). Thus there is the possibility that factors other than browsing may be implicated in the unsatisfactory conditions that occur.

One of the simplest ways to isolate the influence of deer browsing from other factors is by using deer exclosures. If browsing is heavy, the contrast between protected and unprotected areas may be rather striking within a few years. Such contrasts in vegetation have been reported by Dahlberg and Guettinger (1956), Hosley (1956), Grisez (1959), and Shafer *et al.* (1961). Other examples, mostly unpublished, are commonly encountered throughout the Northeast in areas that have a long history of overbrowsing.

This is a report on the height, density, and stocking of commercial species protected and unprotected from deer browsing for several years on experimental clearcut areas on the Allegheny National Forest in northwestern Pennsylvania. The purpose is not only to describe the effects of browsing but also to examine these effects in relation to recent guides[1] for minimum density and stocking of regeneration in Allegheny hardwoods and also in relation to apparent differences in the capability of the areas to regenerate themselves.

The question of these relationships was not initially a part of the study, so the experimental design did not provide for certain variables that otherwise would have been controlled. Nevertheless the results indicate the complexity of the problem of striking a balance between browse utilization and stand regeneration and establishment.

[1] Tentative guides recently adopted by the Allegheny National Forest as a basis for timber management in Allegheny hardwoods.

Exclosures & Methods

Three exclosures were constructed by Allegheny National Forest personnel in pulpwood and small sawtimber stands that had been clearcut for regeneration of black cherry and associated hardwoods. Each exclosure was about 1 acre in size and was protected from deer browsing by a heavy-gage wire fence 8 to 9 feet high. Adjacent to each exclosure was an unfenced check area of equal size.

The exclosures were installed for administrative study of regeneration after clearcutting and as demonstrations of the impact of deer browsing on vegetation. They were selected for our study because, out of a total of about 10 experimental clearcut areas available, they were the only ones in which exclosures had been erected.

It was assumed that the deer population in the vicinity of each exclosure was about the same and that browsing pressure was heavy. There is abundant evidence that the deer population on the Forest has been out of balance with the food supply for many years.

There were differences among the three clearcuttings in age, and in the period of time with and without protection from deer browsing (table 1). None of the differences exceeded about 1½ years. However, the most important difference — the period of time without protection for the exclosed areas — had little influence because it occurred immediately after cutting and while seedlings were still small, snow-covered in winter, and less vulnerable to browsing.

Milacre plots, located by a completely randomized design, were used in sampling. Stems were counted, by species, in 2-foot height classes of 2, 4, and over 5 feet. The unit of measurement was a single stem. The statistical unit for density was the total number of stems per milacre plot for all commercial species (black cherry, sugar maple, red maple, beech, yellow birch, white ash, and aspen), and for black cherry separately. For determination of stocking rate, a stocked milacre plot was considered to be one that contained at least one stem in the above species categories.

Table 1. — Age, treatment, and period of protection from deer browsing for th areas clearcut for hardwood regeneration, Allegheny National Forest

Location of cutting	Date of cutting	Age of clearing, 1960	Treatment	Period protected	Perio unprotec
		Years		*Years*	*Year*
Silver Creek	Winter 1955-56	4½	Fenced Jan. 1958	2½	2
			Unfenced	—	4½
Cherry Grove	Winter 1956-57	3½	Fenced July 1957	3	½
			Unfenced	—	3½
Chappel Fork	Winter 1956-57	3½	Fenced March 1957	3¼	¼
			Unfenced	—	3½

The hypothesis tested at the 5-percent level of significance was that the number of stems per acre and the stocking rate were greater within each fenced area. The "t" test for comparison of two groups of equal size (Snedecor 1956, pp. 87-90) was used to test the hypothesis.

Measurements were also taken on fire cherry; but comparisons in this species, as well as those in any height class for other species, were made only by inspection of the data.

Results & Discussion

The difference in the number of stems for all commercial species (table 2), and for black cherry alone, was not great enough at each location to be significant at the 5-percent level. It may well be that the sample size was too small to detect significant differences in populations with inherently large variation. Subsequent work with seedling regeneration indicated that not less than 40 sample plots are required to estimate means at the 5-percent level. Thus, if it is assumed that the samples in this study gave unbiased estimates of the population differences and variances, then the sample size was too small to judge the differences real.

The negative difference at Chappel Fork (table 2) would nor-

mally be attributed to chance, but it is interesting to speculate that browsing in the unfenced plot may have been selective on sprouts and noncommercial species (fire cherry, shrubs, *Rubus* spp.), thereby reducing competition with the seedlings of commercial species.

The overall stocking rates for commercial species at each location were the same (table 3); for black cherry the only difference — at Cherry Grove — was not significant.

But inspection of the data (table 3) for Silver Creek and Cherry Grove revealed a pattern of a consistently larger number of stems at each height class within the exclosures as compared with those outside. In general, there was also an increase of the magnitude of this difference in each succeeding height class. This was most striking in fire cherry at all locations.

The difference in stocking rates within height classes at each of the two locations followed a pattern somewhat similar to that for density, except for a reversal of the pattern in the 2-foot class for commercial species.

The best explanation for the results found at Silver Creek and Cherry Grove is that deer browsing reduced the height of seedlings, and also the density of seedlings in each height class. The apparent higher rate of stocking in the 2-foot class outside these exclosures could be explained as an accumulation of seedlings

ıble 2. — Summary of tests of the difference in mean number of stems of com-ercial hardwoods protected and unprotected from deer browsing at three l:ations on the Allegheny National Forest

Exclosure location	Treatment	No. of milacre plots	df	$\bar{X}$ No. Stems	Diff. $\bar{X}_1 - \bar{X}_2$	Calculated t	Tabulated t .05
ver Creek	Fenced	12	11	5.7	3.2	1.09	1.72
	Unfenced	12	11	2.5	—	—	—
erry Grove	Fenced	11	10	12.1	9.4	1.41	1.72
	Unfenced	11	10	2.7	—	—	—
appel Fork	Fenced	12	11	61.9	—14.6	<1.0	1.72
	Unfenced	12	11	76.5	—	—	—

Table 3. — Density and stocking rates, by height classes, for hardwood regeneration protected and unprotected from deer browsing after clearcutting, Allegheny National Forest

Location	Stem height class	Commercial spp.		Black cherry		Fire cherry	
		Stems per acre	Stocked plots	Stems per acre	Stocked plots	Stems per acre	Stocked plots
	Feet	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
				SILVER CREEK			
Fenced	2	3,666	67	2,333	50	500	25
	4	1,583	67	1,500	58	667	42
	5+	417	25	417	25	1,833	67
	2-5+	5,666	83	4,250	75	3,000	75
Unfenced	2	2,417	83	1,667	75	166	17
	4	83	17	83	8	0	0
	5+	0	0	0	0	0	0
	2-5+	2,500	83	1,750	75	166	17
				CHERRY GROVE			
Fenced	2	8,454	72	3,091	27	273	27
	4	2,909	36	1,818	27	636	36
	5+	727	54	273	27	1,364	63
	2-5+	12,090	82	5,182	63	2,273	81
Unfenced	2	2,454	82	364	25	182	9
	4	182	18	0	0	0	0
	5+	91	9	0	0	0	0
	2-5+	2,727	82	364	25	182	9
				CHAPPEL FORK			
Fenced	2	59,417	100	50,000	92	2,000	58
	4	2,000	58	1,000	50	1,500	58
	5+	417	25	167	17	3,417	42
	2-5+	61,834	100	51,167	100	6,917	66
Unfenced	2	75,417	100	68,000	100	83	8
	4	750	25	416	25	0	0
	5+	333	33	250	25	0	0
	2-5+	76,500	100	68,666	100	83	8

that did not grow into the 4-foot class because of browsing. Evidence of this was the very low stocking rates in the 4- and over-5-foot classes.

The overall density and stocking rates for all commercial species and for black cherry at Chappel Fork were the highest among the three areas. Browsing pressure at this location appeared to have no harmful effects on the density and stocking rate.

The density and stocking rates for the browsed plots at Silver Creek and Cherry Grove may also be satisfactory with reference to the Allegheny National Forest management guides. For hardwood regeneration from 5 to 10 years after clearcutting on the Allegheny National Forest, the guides specify a density of at least 5,000 woody stems per acre over 1 foot in height, not less than one-third of which must be commercial species; and 70 percent of the sample plots must be stocked with one or more seedlings of commercial species.

The number of stems per acre at the two locations satisfied an

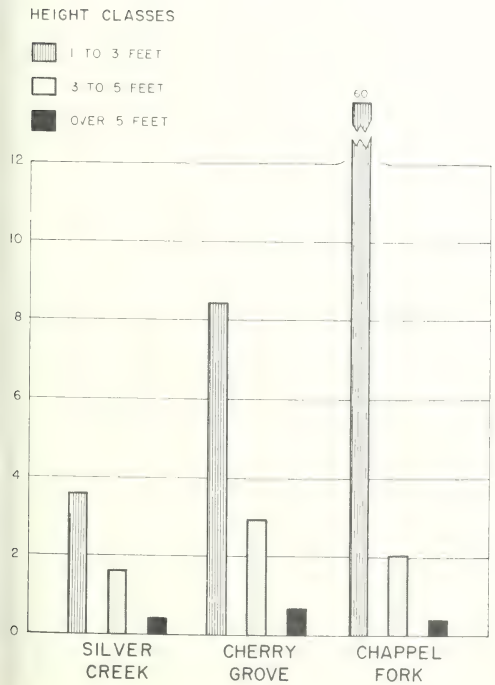

Figure 1. — Density, by height classes, of commercial hardwood regeneration protected from deer browsing on three clearcut areas on the Allegheny National Forest.

important part of these specifications. Whether there was also at least an equal number of noncommercial woody stems was not determined. However, the number of noncommercial stems in clearcut areas generally is greater. And the stocking rates appeared to be satisfactory.

The great difference in the number of seedlings per acre among all locations suggested that there might be inherent differences in the capability of the areas to regenerate themselves. There was a pronounced gradient in the number of stems inside the exclosures (fig. 1), from a low at Silver Creek to a high at Chappel Fork. But this was influenced almost entirely by the density per acre of

Figure 2. — Heavy deer browsing after clearcutting delays the establishment of northern hardwood stands. Open patches like the one in the left foreground were numerous at Silver Creek 10 years after clearcutting.

Figure 3. — The height and density of woody vegetation protected from heavy browsing offers a striking contrast to that in browsed areas. This shows a dense clump of fire cherry after 8 years of protection at Silver Creek.

seedlings in the 2-foot height class. The differences in the next two height classes combined appeared to be unimportant.

Moreover, the rates of stocking in the two height classes were the same (67 percent). This suggested that the number of seedlings per acre in the 4- and over-5-foot height classes was independent of the great variation in density of stems in the 2-foot class, and thus was a better indicator of the capability of these plots (when uninfluenced by deer browsing) to regenerate themselves.

The influence of heavy browsing pressure in the unfenced plots obscured the similarity in density and stocking rates in these two

Figure 4. — Although the density of hardwood seedlings may remain high even under heavy browsing, most stems cannot grow out of the reach of deer. The portion of the fenced plot in the background in this view at Chappel Fork contrasts with conditions in the foreground after 9 years of browsing.

height classes. But they may still be a better indicator of the progress of stand establishment than the overall density and stocking rate. The latter values for Silver Creek and Cherry Grove probably are within the requirements of the tentative guides for regeneration, but the comparatively low number of seedlings and the stocking rate for the 4- and over-5-foot height classes indicate that establishment of these stands beyond the reach of deer was at least being delayed by browsing. This may be the case at Chappel Fork as well.

This effect is important for at least two reasons: (1) any delay

in stand establishment adds to the rotation period, and (2) the vulnerability of commercial seedlings to browsing is increased by the length of time the terminals remain within reach of deer. The hazard associated with this is related to the normal sequence of the effects of heavy deer browsing. The first effect is a reduction in the height of seedlings and, with continued browsing, a reduction through mortality in the number of seedlings.

There was also rather uniform evidence from these results that the effect of browsing was selective against seedlings in the 4-foot height class. There were disproportionately fewer seedlings

Figure 5. — Deer prefer sprouts to seedlings, but heavy browsing pressure in clearcut hardwoods for a period of years increasingly favors the faster-growing sprouts. The vigorous sprout clumps in the immediate background in this picture at Chappel Fork have escaped browsing while most of the seedlings are still being held back after 9 years.

Figure 6. — Successful establishment of northern hardwoods in the Allegheny Plateau means an abundant yield of deer browse and high-quality sawtimber when clearcut at rotation age. The young black cherry shown here is in the poletimber stand adjacent to the Chappel Fork exclosure.

in this class outside of the exclosures at all locations (table 3). This suggests that for these areas under heavy browsing pressure, the density of seedlings in the 4-foot class would yield a more realistic assessment of conditions than the overall number of seedlings per acre. However, no guide is available with which to compare stems per acre in the 4-foot class, nor is there a guide for a minimum stocking rate.

The very low (but probably satisfactory) density of commercial stems for all height classes in the unprotected plots at Silver Creek and Cherry Grove were obviously the result of deer browsing. But this was partly conditioned by the influence of other factors that determined density without browsing; and since this density was not great enough to withstand heavy inroads by deer, both deer browsing and other natural factors are implicated in the low density.

The findings showed that, when subjected to heavy browsing pressure, a density of 5,000 to 12,000 stems of commercial species, and possibly 10,000 to 25,000 stems of all woody species, was not great enough to prevent a delay in stand establishment. There was some evidence that even 60,000 stems per acre of commercial species was not great enough to prevent a delay at Chappel Fork.

From general observations of all areas made 5 years after the study (figs. 2 to 6) it was evident that establishment of the stands was still being delayed by browsing. Numerous patches were found, some large, in which there were no stems of commercial species over 5 feet high.

Conclusions

Several general inferences can be drawn from these results. The most obvious is that heavy browsing in clearcut areas in northern hardwoods can reduce both the height and density of commercial reproduction. The effect seemed to be greatest on stems in the 3- to 5-foot height range, and this carried over to produce an even lower density of stems in the over-5-foot height class.

A satisfactory density and stocking rate for seedling regeneration, determined by current but tentative guides, carries with it no complete assurance that a stand will be established above the height to which deer will browse (4½ to 5 feet). There may at

least be a delay in establishment. This adds to the rotation period and also increases the vulnerability of seedlings to browsing. It seems likely that, the longer the delay, the greater the risk of a further reduction in the density of stems. If this is assumed, then the effect of browsing would be more harmful when seedling density is low to begin with.

The influence of repeated browsing on the growth rate and form of seedlings and the quality of wood produced was not determined, but unpublished results of a study of simulated deer browsing on hardwood seedlings showed that black cherry commonly responds by multiple sprouting from the root collar.

Where browsing pressure is heavy in regeneration stands over 3 years of age, the density and stocking rate of stems above 3 feet in height probably are a better indicator of the progress of stand establishment than if stems under 3 feet are included. Guides for minimum density and stocking rate should be developed for stems above 3 feet in height for areas with large deer populations.

A limited amount of evidence indicates that in seedling stands from 3 to at least 5 years of age, which are not influenced by heavy browsing, the density of stems per acre over 3 feet high is independent of the great variation in those under 3 feet high. The taller stems appear to be a better indicator of the capability of stands to regenerate themselves.

A preference of deer for fire cherry resulted virtually in a biological control of the species.

■

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by Wilbur F. LaPage

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SUCCESSFUL PRIVATE CAMPGROUNDS

A study of factors that influence the length and frequency of camper visits

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1967
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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

SUCCESSFUL PRIVATE CAMPGROUNDS

A study of factors that influence the length and frequency of camper visits

The Author

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This study, a cooperative venture of the New Hampshire State Planning Project and the U. S. Forest Service, is based on data supplied by approximately 1,000 visitors to New Hampshire's 108 commercial campgrounds in 1964.

THE GROWTH OF PRIVATE CAMPGROUNDS

PRIVATE enterprise now provides the majority of camping facilities in the Northeastern States. Though it was the national and state forests and parks that pioneered in providing outdoor recreation facilities for the general public, the privately owned and operated campground has now developed a large following of its own. An estimated 1,000 commercial campgrounds were in operation last year in the 14 Northeastern States from Maine to Ohio. The ratio of private campgrounds to public campgrounds is 3 to 1 for the region as a whole, and goes as high as 7 to 1 in Maine. The only Northeastern States that now have more public than private campgrounds are Maryland and West Virginia.

Because of our interest in the use of forest land as potential income-producing recreation sites, we have directed some research toward this phenomenon of the private campground. In an exploratory study in New Hampshire, we have delved into the behavior patterns of campground visitors in an attempt to determine what factors spell success or failure for the private campground.

DEFINING SUCCESS

Success means many things. And, after interviewing more than 100 owners of recreation enterprises, we conclude that one thing it does not seem to mean is money — at least not in the early years of business. But the private camping industry has not been around long enough to have produced enough bona fide business failures and successes for objective analysis. So we will use other ways of describing success and hope that they will ultimately agree with financial success.

One of the more obvious substitutes for a cost-and-return ledger is attendance in terms of the percent of capacity that a recreational facility is used from year to year. In an attempt to provide planning and investment guide lines, several management decisions and locational variables were studied for their effects upon attend-

ance in 1963 at private campgrounds in New Hampshire.[1] Figures for 85 enterprises indicated that attendance at campgrounds varies significantly with campground age, geographic location, number of family units, size of investment, and presence of water for swimming.

The major limitation to the use of attendance as an index of enterprise success is that, like gross income, it says very little about an enterprise's potential. Even rising trends in attendance from year to year may be more a reflection of changing market demand, or advertising policy, than evidence of the return of satisfied campers.

Some of the substitutes for describing potential enterprise success involve certain characteristics of campers and their visits. These characteristics fall into three broad classes: (1) attitudinal variables, such as campers' satisfaction and intentions of returning for future visits; (2) behavioral variables, such as the length of visits and the frequency of past visits; and (3) demographic variables such as camper origins, destinations, distances traveled, past camping experience, and so forth.

Most attitudinal variables are difficult to describe and to tie a dollar value to, and demographic variables are probably not very consistent indicators of a recreation area's attractiveness.[2] Consequently our study emphasized the use of behavioral variables as measures of camper satisfaction directly, and enterprise quality indirectly.

However, relating the frequency and length of camping visits to differences in camping enterprises is somewhat complex because each of the factors — length of visit, frequency of past visits, and plans for a future visit — are strongly inter-related and are closely tied to a camper's expressed preference in campgrounds (fig. 1). For example, the camper who states a preference for privately developed facilities is far more likely to make an extended visit to a private campground than is one who says he prefers publicly

[1] LaPage, Wilbur F. SUCCESS OF CAMPGROUNDS STUDIED AS GUIDE TO RECREATION PLANNERS. U. S. Forest Serv. Res. Note NE-43, 7 pp. NE. Forest Exp. Sta., Upper Darby, Pa., 1966.

[2] Outdoor Recreation Resources Review Commission. THE QUALITY OF OUTDOOR RECREATION AS EVIDENCED BY USER SATISFACTION. 95 pp., illus., 1962.

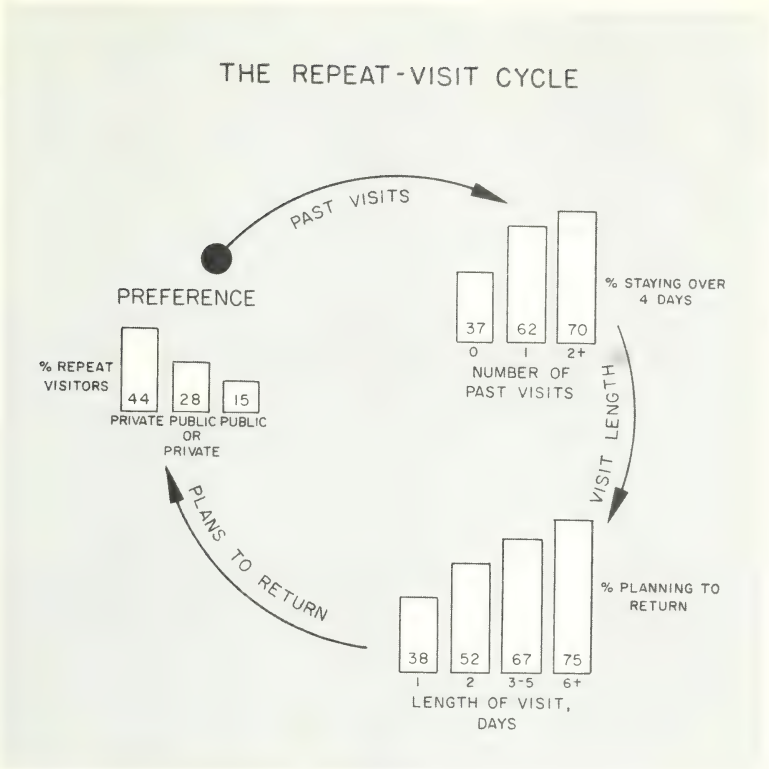

Figure 1. — A repeat-visit cycle among campers seems to begin with a visitor's preference or lack of preference for privately owned campgrounds. The number of past visits to the campgound then affects the length of a current visit. (Increasing familiarity with the campground and the surrounding region promotes longer visits.) And, finally, current visit length is a strong factor in determining the camper's intentions of returning in the future.

owned facilities. And, once having made a long visit, he is much more likely to plan on returning to that campground in the future.

This interrelationship means that whenever visit lengths and frequencies are compared between campgrounds, it is necessary to segregate the variation caused by campground differences from that due to visitor preference and its effects on behavior. That is, findings concerning the relative advantage of one type of enterprise over another must be qualified by reference to uniform categories of visitor preferences and past camping visits.

IMPLICATIONS FOR RECREATION AREA PLANNING

How Much And How Big?

The first consideration of interest to most prospective campground developers is cost. Certainly there is some relationship between the amount of capital invested and enterprise success. We know that nation-wide there are about 87,000 commercial outdoor recreation enterprises and that about half of these have an investment of less than $10,000, only one employee, and do a very low volume of business.[3] But even a small campground, with modern facilities, can seldom be built for less than $10,000 today. So we chose $15,000 as an arbitrary dividing line, and compared visits at campgrounds costing more and less than that amount to develop (table 1). Not surprisingly, campers at the areas having larger capital investments stayed longer on the average, came back more,

[3] Crafts, Edward C. Speech given before the American Camping Association, Chicago. U. S. Dep. Interior news release, March 11, 1966.

Table 1. — A comparison of camper behavior at private campgrounds, by amount of invested capital[1]

Item	Size of investment	
	$15,000 or less	Over $15,000
Sample size (campers) . . . . . number . .	321	623
Camping over 3 days*** . . . . . percent . .	30	52
Average length of visit*** . . . . . days . .	2	4
Repeat visitors*** . . . . . percent . .	19	35
First-time visitors who intend to return in the future, according to camper preference in campgrounds:		
Prefer private ownership*** . . percent . .	65	84
Like either type*** . . . . . percent . .	57	73
Prefer public ownership* . . . . percent . .	35	52

[1] The proportions of campgrounds having investments of more than, and less than, $15,000, when tested by Chi-square, are significantly different at: *the 0.05 level; and ***the 0.005 level.

Table 2. — Length of visit, and intention of return, according to campground size and region of location

Region	Camping over 3 days		Planning to return	
	At small campgrounds	At large campgrounds	At small campgrounds	At large campgrounds
	Percent	*Percent*	*Percent*	*Percent*
Northern***	22	50	55	73
Central*	50	63	66	75
Southern[1]	27	45	66	85
State-wide***	34	56	62	74

* Significant at the 0.05 level.
*** Significant at the 0.005 level.
[1] Sample size in Southern New Hampshire is about ⅓ that of each of the other regions, and the Chi-square values in this region are not signficant at the 0.05 level because they have been corrected for the small sample sizes.

and planned to return in the future, all in significantly greater proportions and regardless of their past visits or their expressed preferences for public or private ownership.

Along with the question of "How much?" comes the equally common question of "How big?". Here again the larger campgrounds, containing at least 70 family units, had a decided advantage on every count. Approximately 36 percent of the visitors at large campgrounds had visited the enterprise at least twice, as opposed to 21 percent at the smaller enterprises. Lengths of visits and plans to return for future camping visits were significantly greater at large campgrounds in every region of the State (table 2 and fig. 2).

This effect of enterprise size upon visitor behavior is partly a reflection of the effects of capital investment because large campgrounds usually cost more to build (table 3).

What can these findings mean in terms of economical campground operation? The average number of days that a camper spends at a campground has a direct effect upon management costs. Short visits produce a faster turnover, more work, and consequently more labor expense per visit. Because large campgrounds generally produce longer visits, they have a cost advantage. For example, a 100-unit campground may be able to operate with the

Figure 2. — Locations of the private campgrounds in New Hampshire whose visitors were surveyed by questionnaires in 1964.

same number of employees as a 50-unit campground, if its visitors stay at least twice as long.

Since big campgrounds also demonstrate increased visitor return rates, they have a second advantage of a larger guaranteed income. Three-fourths of the campers at big campgrounds expressed a desire to return for a future visit. And, although these campers were not asked to pinpoint the date of their intended return, it seems reasonable to assume that many intend to come back once, or more than once, during the following year. By being extremely conservative, and dropping this intended return rate down to the actual past visit rate, it may be possible to assign a realistic dollar value to this measure of customer satisfaction.

For example, a 50-unit campground where 21 percent of each year's visitors are repeat customers who stay for 2 days, and pay $2 per campsite per day, can expect to earn a minimum income from

Table 3. — Distribution of campground sizes (family units) according to the total amount of invested capital

Investment	Number of campgrounds			
	Size not reported	Small, less than 30 units	Medium, 30-69 units	Large, over 69 units
$15,000 or less	9	35	12	4
Over $15,000	3	4	6	15
Not reported	—	8	4	8

repeat visitors of $1,050 if it is operating at an average of one-half of capacity during a 100-day season. At the same time, a 100-unit campground operating at one-half capacity, and charging the same fees, but 36 percent of whose visitors are repeaters who spend 4 days per visit, can expect to make $3,600. This represents a minimum dollar advantage of 240 percent, on repeat visitors alone, at large campgrounds.

So much for theory. Big campgrounds still cost more to develop than small ones. And they can still expect to have one or more lean years in the beginning. After all, there are no repeat visitors during the first year, and probably very few during the first 4 to 5 years of operation. So the best advice seems to be to start small, and expand when necessary.

The real key to these relationships is less a question of enterprise size than it is one of enterprise quality. Few big campgrounds started out big. Most grew that way in response to the demands of satisfied customers. In fact then, large enterprises are simply successful enterprises, and size is just one index of many things that reflect that success, including the owner's personality, the number of recreational outlets available, and the quality of the campground's development and management.

Should the Owner Be A Camper Himself?

Since quality seems to be the key to success, what is it?, and how can it be recognized in potential form among prospective managers

Table 4. — A comparison of visitor characteristics at campgrounds owned by campers and those owned by non-campers

Item	Camping owners	Non-camping owners
Sample size (campers) . . . . . number . .	542	489
Average visit*** . . . . . days . .	3	5
Camping for more than 3 days*** . . . . . percent . .	41	50
Visited the campground before*** . . . . . percent . .	25	36
First visitors expecting to return to large campgrounds, by campground preference classes:		
Prefer private ownership . . . . . percent . .	66	81
Like either type*** . . . . . percent . .	33	60
Prefer public ownership*** . . . . . percent . .	53	80

*** Significant at the 0.005 level.

and in their developable resources? One of the common criteria being advanced is that recreation developers should themselves be recreationists. It would probably be hard to find some who are not. But taking this suggestion to a more specific level, we looked at New Hampshire's 108 commercial campgrounds in terms of whether or not the owner was himself a camper.

If our findings are conclusive beyond the borders of New Hampshire, being a camper is hardly an endorsement for prospective campground ownership. Significant reductions in visit lengths, frequencies, and return intentions were evident at the camper-owned enterprises. These differences were independent of the effects of campground size and camper preference. In fact, even the large camper-owned enterprises were less effective in influencing return visits among campers who had already expressed a preference for private developments (table 4).

Although these findings do not mean that all camping managers are less successful than all non-camping managers, they do point out some rather substantial and unexplained differences. One possible explanation is that many of these camper-owned enterprises were small, and were probably operated on a part-time extra-income basis. This type of operation often fails to produce a quality camping experience.

There is also the possibility that many campers go into this business with the visionary idea that they are going to provide "that long unfilled need of a camper's campground." These people, in providing their own ideal campsite for everyone, may fail to realize that camping means many things to many people. To meet these diverse needs, differences have to be designed into the campground, allowing for trailer sites, tent sites, open sites, shaded sites, some close together, and others far apart. The non-camper, on the other hand, not being afflicted by this sentimental bias, may view the problem of campground design from a business standpoint and try to capitalize on these differences.

Importance of Water And Campground Location

Among physical resources, water seems to be an almost universally necessary ingredient for a high-quality experience and a successful camping venture. The still waters of lakes and ponds are apparently more attractive than streams and rivers. In examining lakefront campgrounds, riverfront campgrounds, and dry campgrounds, we found a persistent decrease in visit lengths, frequencies, and return intentions. When the effects of campground water attraction are added to those of campground age and past attendance of visitors, the effect on current visit length is pronounced. New visitors to newly developed and dry campgrounds camp for an average of 1 day, while repeat visitors to older lakefront campgrounds spend an average of 10 days camping per visit (table 5).

Regional location has a lot to do with recreation quality. This attribute is difficult to measure because the competition is usually most severe in regions that have the best recreational attractions. However, the availability of swimming facilities at the campground, for example, was found to have less influence on visit length in regions where water was abundant and campers could easily drive to nearby public beaches.

In general, regions that offer a variety of recreational opportunities to the camper tend to promote longer and more frequent visits. But there may be disadvantages to these locations as well. For

Table 5. — Length of visit of repeat visitors and first-time visitors, according to age of campground development and on-site attraction

Age and attraction of development	Median length of visit	
	Repeat visitors	First-time visitors
	Days	*Days*
1 to 4 years:		
Lake	9	3
River	4	2
Non-water	([1])	1
Over 4 years:		
Lake	10	3
River	5	3
Non-water	3	1

[1] Insufficient responses to analyze.

example, vacation regions often have well-established tourist seasons, and the campground located within them is forced to conform to the prevailing seasonal use pattern. The same camping enterprise located nearer to an urban center might substantially increase its income simply by being available for a longer camping season.

IMPLICATIONS FOR RECREATION MANAGEMENT

In studying the factors that are likely to influence visit behavior at private campgrounds, we soon became aware that the factors that may have the most influence are those that also seem to have the least direct applicability to recreation-area planning. For example, many variables of campers themselves, their preferences in campgrounds, their reasons for camping, their past camping experiences, and their equipment undoubtedly exert much stronger impacts on behavior than a campground's size, location, or attractiveness.

The Camper And What He Wants

Many of these variables of the camping population can be effectively used by the alert campground manager to influence visit behavior. For example, tent campers stay longer than their more mobile neighbors who use trailers (table 6). When separate areas are provided for each, tent campers will not be subjected to excessive incoming and outgoing trailer traffic, which may not only be objectionable but may give the tenter the idea that he should be leaving too. Also, trailer campers, because of their superior mobility, camp much more frequently; and providing special facilities for their use may help to produce a higher rate of return visits.

Since long visits are associated with repeat visits, the enterprising manager may be able to capitalize on this relationship through the use of reduced-fee incentives for repeat visits and for visits longer than a weekend (table 7). This assumes, of course, that the enterprise has an attraction sufficient to make the minor incentive of an occasional free day's camping worthwhile.

Even camper preferences for private and public ownership have implications that are useful to campground management. Of the 1,031 campers in this study, 36 percent preferred private areas, 20 percent favored public ownership, and 38 percent liked both types of campgrounds equally well. These figures indicate that commer-

Table 6. — Lengths of camping visits, and annual frequency of camping trips, among campers using three different types of camping equipment

Item	Equipment		
	Tents	Tent trailers	Travel trailers
	Percent	*Percent*	*Percent*
Camping for one week or more***	35	29	23
Camp more frequently than 4 visits per year***	22	43	55

*** Significant at the 0.005 level.

Table 7. — The percent of first-time visitors and repeat visitors planning to return in the future, according to length of current visit classes

Item	Visit length (days)					
	1	2	3	4-5	6-10	11 or more
First-time visitors to return***	38	52	65	70	72	79
Repeat visitors to return	82	83	93	93	95	96

*** Significant at the 0.005 level.

cial campground ownership already enjoys a distinct competitive position in the camping market. By knowing something about the basis for these preferences it may be possible to improve that position.

Both groups that expressed preferences felt that their favored camping areas provided superior facilities. Many campers who prefer public campgrounds pointed to the supposed lower cost of visiting these areas. And campers who prefer private developments frequently mentioned the convenience of being able to reserve a campsite in advance of their arrival. The following tabulation shows the basis for preferences given by these groups:

Basis for preference	*Public campgrounds (percent)*	*Private campgrounds (percent)*
Better facilities	37	48
Better maintenance	21	11
Reserved campsites	—	26
More economical	21	—

It is interesting to note that private campgrounds seem to have an image of good facilities but poor maintenance, on the basis of these preference statements. But, in further questioning about the total image of both public and private campgrounds, this supposed maintenance deficiency was not evident.

Advance Reservations And Camper Organizations

Two further points are worth noting about this tabulation of preferences: the desire of many campers for an advance-reservation policy, and the fact that neither preference appears to be very substantively founded. The latter point could probably be pursued to advantage in campground advertising by emphasis on the fact that private camping is as good, or better, than public.

Since reservation camping is a service that many public agencies have avoided, or have had difficulty with, commercial campgrounds have this field wide open to them. Forty-one of the campgrounds in this survey, which had been in business for at least 1 year, claimed to have a predominantly advance-reservation business. Another 44 indicated that most of their visitors arrived without reservations.

Visitors to these two groups of campgrounds differed in several important ways. Visitors to reservation campgrounds apparently camp more frequently, spend more days per visit, and are more likely to have visited the campground on at least one earlier camping trip (table 8).

Table 8. — Visit characteristics at enterprises where either a majority or minority of the visitors tend to reserve their campsites in advance

Item	Business is predominantly—	
	Reserved campsites	Unreserved campsites
Sample size (visitors) . . . . . number . .	638	281
Average length of visit*** . . . . . days . .	4	2
Camping over 3 days*** . . . . . percent . .	56	38
Repeat visitors*** . . . . . percent . .	36	26
First-time visitors who intend to return* . . . . . percent . .	62	52
Take more than 4 camping trips per year* . . . . . percent . .	35	28

* Significant at the 0.05 level.
*** Significant at the 0.005 level.

Numerous other camper variables and attributes have potential management implications for the alert campground owner. For example, 31 percent of the campers in this study said they were members of one or more camping organizations. As a group, these people have been camping longer, and average more camping trips each year, than do the non-affiliated campers. Among organization members, 59 percent go on more than 4 camping trips each year, while only 26 percent of the non-members camp this often. More than one-third of the campers who have been camping for more than 5 years belong to an organization of campers, hikers, or trailer owners.

Although campers who prefer public campgrounds are slightly less likely to belong to a camping organization, those that do seem to be more favorably impressed with private campgrounds, and consequently they plan to return in the future in significantly greater proportions. Since organization members are frequent campers, the campground owner who can effectively appeal to this clientele should be able to develop a fairly stable recreation enterprise. It is obviously very important to be aware of these groups, advertise in their magazines, pay attention to their membership surveys, and learn what it is that they want in the way of a camping experience.

IMPLICATIONS FOR FUTURE RESEARCH

Many characteristics of campers and their visits provide useful hints for more effective campground planning and management. An understanding of the campground factors that influence visit lengths and frequencies can be invaluable for answering management questions of where to locate, what facilities to provide, and how much to spend. Camper-oriented factors, such as preferences, equipment, and past camping experiences, which influence visit behavior, also provide numerous clues to the camper's interpretation of a quality outdoor recreation experience.

Although this study is based upon the voluntary response of a non-random group of private campground visitors, in one state, and in one year, a few general conclusions are worth noting:

- Behavioral variables like visit length and frequency can be very useful in analyses of recreation enterprise potential, if contaminating influences such as preferences, purpose of visits, and past visits, are carefully controlled.
- Analyses such as this provide only the superficial and measurable clues to enterprise quality and success. Quality in recreational experiences also involves a lot of good taste, alert business judgment, and hard work.
- Studies like ours may help to take some of the risk out of private forest-recreation enterprises. However, an element of risk will always remain simply because all of the factors that affect the market, supply, population, and policy are continually changing.

■

APPENDIX

Table 9. — Responses to questions asked in the private campground visitor questionnaire

Question	Response[1]
Date of visit (grouped in two-week periods)?	*(Percent)*
June 16 to June 30	4.9
July 1 to July 14	13.0
July 15 to July 31	27.3
Aug. 1 to Aug. 18	27.4
Aug. 19 to Aug. 31	8.7
Sep. 1 to Sep. 15	13.4
After September 15	1.5
How many days will you stay at this campground?	
One	16.2
Two	17.2
Three	17.9
Four to seven	23.6
Eight to fourteen	17.7
Fifteen or more	9.2
On the average, how often do you take camping trips like this one?	
First camping trip	9.8
Less than one trip per year	1.3
One trip each year	24.6
Two trips each year	13.5
Three or four trips each year	15.4
More than four trips per year	34.7
Have you ever camped at this campground before?	
Yes	30.4
Approximately how many times have you camped here?[2]	
Once	30.4
Twice	14.7
Three times	12.1
Four times	9.6

[1] All percentages based on 1,031 responses unless otherwise indicated.

[2] Percentages based on 313 responses from people who had previously visited the campground.

CONTINUED

Table 9. — (Continued)

Question	Response[1]
	(Percent)
Five times	8.3
Six times	4.2
Seven times	2.9
Eight times	2.9
More than eight times	13.7
Do you plan to camp here again?	
Yes	69.4
No	7.0
Undecided	23.2
Approximately how many years have you been camping?	
One	10.1
Two	14.9
Three	13.6
Four	9.1
Five	9.3
Six to ten	18.2
Eleven to twenty	13.3
More than twenty	4.3
Have you camped at any other privately-owned campgrounds in New Hampshire?	
Yes	37.3
How many other private campgrounds have you visited?[3]	
One	48.6
Two	23.4
Three	9.1
Four	3.4
Five	3.0
Six	3.1
Over six	2.4
Have you camped at any of New Hampshire's State Parks?	
Yes	39.8

[3] Percentages based on 385 campers having visited other private areas.

CONTINUED

Table 9. — (Continued)

Question	Response[1]
	(Percent)
How many New Hampshire's State Parks have you camped at?[4]	
One	57.6
Two	21.5
Three	13.2
Four	3.7
Five	1.7
Over five	.5
Have you camped at any of the campgrounds in the White Mountain National Forest?	
Yes	29.4
How many White Mountain National Forest campgrounds have you visited?[5]	
One	48.5
Two	21.8
Three	10.9
Four	4.6
Five	3.0
Over five	3.0
In general, do you prefer to camp at private campgrounds, like this one, or at public areas such as the State Park and National Forest campgrounds?	
Prefers privately-owned campgrounds	36.1
Prefers campgrounds on public land	19.7
It makes no difference	38.0

What are the most important reasons for your preference of:[6]

	Private campgrounds	*Public campgrounds*
Like the managers	5.9	1.0
Like the other campers	1.6	1.5

[4] Percentages based on 410 campers having camped at New Hampshire State Parks.
[5] Percentages based on 303 campers having camped in the White Mountain National Forest.
[6] Based on 373 campers who prefer private developments, and 203 campers who prefer public. Neither column adds to 100 percent because some campers gave more than one reason.

CONTINUED

Table 9. — (Continued)

Question	Response[1]	
		(Percent)
	Private campgrounds	*Public campgrounds*
More to do (activities)	2.4	3.4
More economical	2.7	20.7
Better maintenance	10.7	21.2
Better facilities	47.6	36.9
Easier to find and get to	3.2	2.0
Advance reservations	25.8	2.0
Other reasons	28.7	41.3
No reason given	10.7	4.9
Have you camped in any states other than New Hampshire?		
Yes		87.5
Which of the following most nearly describes your one most important reason for going camping?		
Enjoy meeting and visiting the type of people who camp		5.0
An economical vacation or weekend trip		26.1
Enjoy seeing new country		17.5
Enjoy the outdoors and its recreational opportunities		31.2
Other reasons (or combinations of the above)		20.2
What type of camping equipment did you bring on this trip?		
Collapsible camping trailer		22.0
Travel trailer		22.3
Tents		49.2
Are you a member of any camping or outdoor organization?		
Yes		30.6
Which of the following statements would you use to describe both private and public campgrounds?		
	Private campgrounds	*Public campgrounds*
Outstanding scenery	12.2	51.2
Attractive natural landscape	15.3	49.0
Pleasant outdoor surroundings	34.9	28.8
Many things to do and see nearby	34.9	20.3
Many vigorous outdoor activities	25.5	23.9
Quiet and restful atmosphere	40.0	27.6

CONTINUED

Table 9. — (Continued)

Question	Response[1]	
		(Percent)
	Private campgrounds	*Public campgrounds*
Not enough privacy	24.2	29.3
Uncertain of getting a campsite	4.6	65.8
Developed with many modern conveniences	60.1	10.8
Less developed, located close to town	21.3	11.3
Primitive surroundings, few conveniences	5.2	39.2
Management extremely helpful	59.3	8.4
Management usually unavailable	5.0	18.9
Management is very business-like	19.2	22.1
Managers don't make you feel welcome	3.2	14.1
Campground always clean and attractive	37.9	19.8
Campground cleaned only occasionally	9.6	11.9
Facilities are poorly maintained	8.5	12.2

Table 10. — Distribution of private campground enterprises and camper response according to selected attributes of campgrounds and their managers

Item	Campgrounds	Visitor response
Campground size:	*No.*	*Percent*
Under 70 family units	76	40
70 or more units	24	60
Campground age:		
One to two years	31	12
Three to four years	24	30
Over four years	53	58
Regional location:		
Northern (White Mountains)	35	44
Central (Lakes, Dartmouth-Sunapee)	53	44
Southern (Monadnock, Merrimack Valley, and Seacoast)	20	12
On-site attraction:		
Lake or pond	45	48
River or stream	39	41
Non-water attraction	22	11
Manager - camper:		
Manager an active camper	71	53
Manager not a camper	37	47
Campground owner associations:		
Member	33	70
Non-member	75	30
Management incentives:		
Income incentives	34	40
Interest in the outdoors	44	46
Influence of others and public pressure	30	14
Advance reservation policy:		
Business is predominantly by reservation	41	62
Business not predominantly by reservation	44	28
Size of investment:		
$15,000 or less	60	31
Over $15,000	28	60

THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Stump Sprouting

of Four Northern Hardwoods

by Dale S. Solomon
and Barton M. Blum

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Stump Sprouting of Four Northern Hardwoods

The Authors . . .

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Introduction

FRESHLY cut stumps of most northern hardwood species commonly develop sprouts from previously dormant buds at or slightly above the root collar. These sprouts are of interest and concern to both timber and wildlife managers.

Where vigorous sprouts compete with more desirable regeneration, the timber manager often is concerned with retarding sprout development through mechanical, chemical, or other means. However, under some conditions sprout development may be accepted or even encouraged — for example, where a forest is being managed for bulk products. Also, sprouts from small stumps may be acceptable even where sawtimber is the management objective.

The wildlife manager is interested in sprout growth primarily as browse for deer. Generally, for a given site and hardwood timber type, sprout growth will produce more browse than seedling growth. Because the reach of the deer determines browse availability, the wildlife manager is interested in the height development of sprouts as well as in the number of sprouts per stump or per acre.

Information about the relationship of sprouting to stump characteristics and stand conditions would aid both timber and wildlife managers in developing appropriate management programs. Also,

such information should aid in the development of multiple-use management plans for areas that are to be devoted to both timber and wildlife production. As a start toward meeting these needs, a study of sprout occurrence and development in recently cutover northern hardwood stands was conducted in the White Mountains of New Hampshire.

Methods

Four cutover areas on the White Mountain National Forest were chosen for study. These areas, totaling about 500 acres, represented clearcutting and light, medium, and heavy partial cuttings. The clearcutting was of the heavy commercial type. All four areas were cut during the dormant season of 1962-63.

Stumps of four major northern hardwood species were sampled: yellow birch (*Betula alleghaniensis,* Britton), paper birch (*B. papyrifera,* Marsh), sugar maple (*Acer saccharum,* Marsh) and red maple (*A. rubrum,* L.). Beech (*Fagus grandifolia,* Ehrh.) and white ash (*Fraxinus americana,* L.), which also are important northern hardwood species, were not included in the study. Beech, not generally regarded as a very important browse species, produces mostly root suckers or stool sprouts (short-lived adventitious sprouts arising from the cambial area at the top of a stump) rather than true stump sprouts. White ash, although a preferred browse species, was not abundant enough to provide an adequate sample.

A total of 172 stumps, 6 inches in diameter or larger and about equally divided among the four species, were selected for analysis. Within these restrictions, selections were at random. The number of stumps by species was as follows: red maple, 42; sugar maple, 44; paper birch, 42; and yellow birch, 44.

Measurements were taken during the summer of 1964, the second growing season after the stands were cut. The number of sprouts at each stump was recorded; any sprout forking within 2 inches from the point of origin was counted as two (or more) sprouts. For estimating vigor, heights of the three tallest sprouts at each stump were measured to the nearest 0.1 foot. If any of these three sprouts had been browsed recently, height before

browsing was estimated by measuring the current year's growth on an adjacent unbrowsed sprout and adding this length to the previous year's growth of the browsed sprout.

Four independent variables were determined or estimated as described below:

1. *Density of the residual stand* was expressed as the basal area per acre in trees 5.0 inches d.b.h. and larger immediately surrounding the sample stump. Basal area was measured in square feet with a 10-factor prism, using the stump center as the point of pivot.

2. *Diameter of the parent stump* was recorded as the average of the widest and the narrowest dimensions measured to the nearest 0.1 inch about 1 foot above ground. Because of the commercial type of cutting, stumps less than about 6 inches in diameter were not available for measurement.

3. *Age of the parent tree* was determined, if possible, from ring counts at stump height. Where annual rings were obliterated, age estimates were developed from the ring counts on nearby stumps.

4. *Vigor of the parent tree* was based on width of the outer 10 annual rings measured to the nearest 0.1 inch. Where radial growth varied considerably, an average width was computed from measurements at several randomly selected places around the stump perimeter. Both the 10-year diameter increment and the 10-year basal-area increment were calculated.

The data covered an adequate range of values for each independent variable. For all species combined, parent stumps ranged from 6 to 25 inches in diameter. Basal area of the residual stands varied from 0 square feet to 120 square feet. Vigor of the parent trees in terms of 10-year basal-area increment ranged from 0.02 to 0.50 square feet, and their ages ranged from 35 to 200 years.

Multiple regression screening techniques were used to relate both the number of 2-year-old sprouts and the average height of the three tallest sprouts to selected combinations of the independent variables. Stumps that had no sprouts were eliminated from the analysis of sprout height. Several transformations were applied to the dependent variables to determine the best fit. The transformation that produced the highest correlation for both dependent variables was the logarithm to the base 10 plus 1. The final regression equations were selected on the basis of high multiple correlation, low standard error of estimate, and practicality for application in the field.

Results

Red Maple

As expected, red maple was the most prolific sprouter among the four species in the study. The number of sprouts per stump was related to both the past 10-year basal-area increment of the parent tree and to the interaction of stump diameter and basal-area increment, as shown in equation I below:

$$[I] \quad Y = 0.995 + 11.600\ (X_2) - 0.704\ (X_1)\ (X_2)$$

where Y is the $\log_{10}$ (number of sprouts + 1), X_1 is the average stump diameter in inches, and X_2 is the past 10-year basal-area increment in square feet. This equation has both regression coefficients significant at the 1-percent level, a multiple correlation coefficient of 0.49, and a standard error of estimate of 0.074.

The number of sprouts increased with increasing basal-area increment for stumps up to about 16 inches in diameter. Above 16 inches, the number of sprouts decreased with increasing basal-area increment (fig. 1).

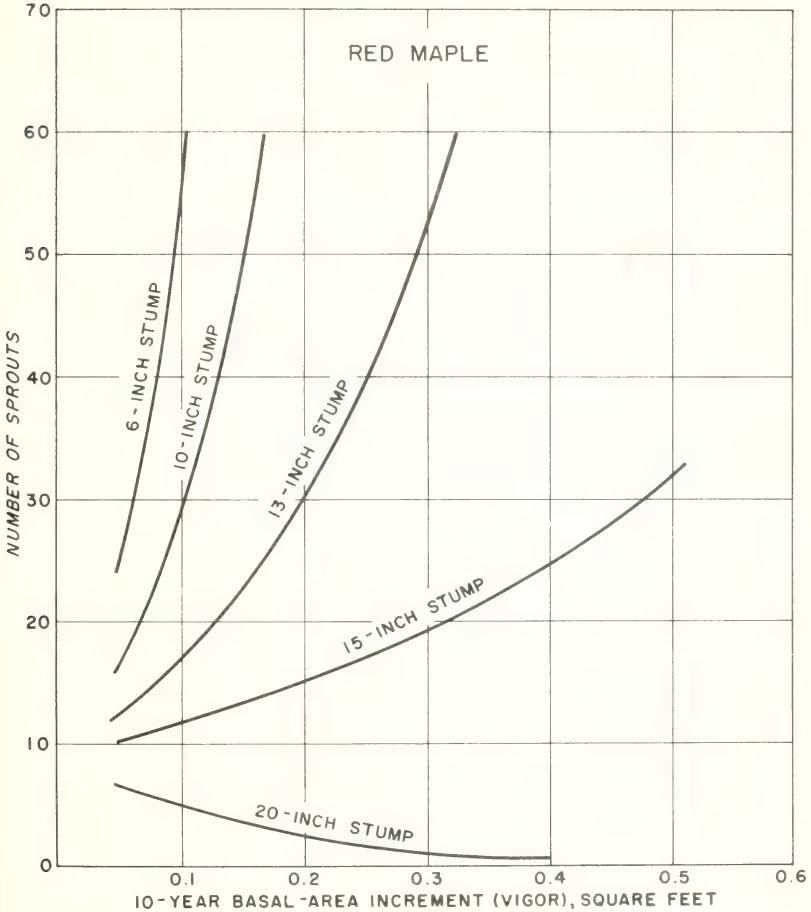
Because the past 10-year basal-area increment is difficult to measure on standing trees, equation I is not convenient to use for prediction purposes. For practicality, equation II is better:

$$[II] \quad Y = 0.779 + 0.134\ (X_1) - 0.007\ (X_1)^2$$

where Y is $\log_{10}$ (number of sprouts + 1) and X_1 is the average stump diameter in inches. The regression coefficients are almost significant at the 5-percent level in equation II. The multiple correlation coefficient is 0.42, and the standard error of estimate is 0.077.

This equation indicates that, for red maple, the number of sprouts increased with increasing stump diameter up to about 9 inches; beyond 9 inches, the number of sprouts decreased (fig. 2). Sprouting was most prolific on stumps in the range of about 6 to 12 inches in diameter. These results are in accord with findings by Keetch (3) that sprouting of hardwoods increases with tree size up to 5 inches d.b.h. (approximately 7 inches in stump diameter)

Figure 1. — Relationship of number of 2-year-old red maple sprouts per stump to the last 10-year basal-area increment for five stump diameter classes.



and then decreases. Other studies conducted in oaks and sugar maple support the results expressed by these equations: that, as the tree diameter increases, the number of sprouts per stump decreases (*1, 2, 5, 6, 7*).

Average height of the three tallest red maple sprouts per stump was inversely related to the 10-year basal-area increment of the parent tree and to tree age. The most accurate expression of this relationship was:

[III] $Y = 0.961 - 1.484\ (X_1) - 0.003\ (X_2)$

where Y is the $\log_{10}$ (average height in feet of the three tallest sprouts + 1), X_1 is 10-year basal-area increment in square feet, and X_2 is tree age (fig. 3). The regression coefficients are significant at the 5-percent level. The multiple correlation coefficient is 0.478, and the standard error of estimate is 0.030.

Because basal-area increment is not easily measured in the field, we tested other equations that did not involve this variable in the hope of finding a more convenient one to use. However, these other equations all had considerably higher standard errors of estimate for predicting sprout height.

The inverse relationship between sprout height and stump age was to be expected because older plant material generally exhibits less vigor in vegetative reproduction than younger material. However, the inverse relationship between sprout height and 10-year basal-area increment in red maple is not so easily explained. Possibly, the greater number of sprouts produced on stumps of the

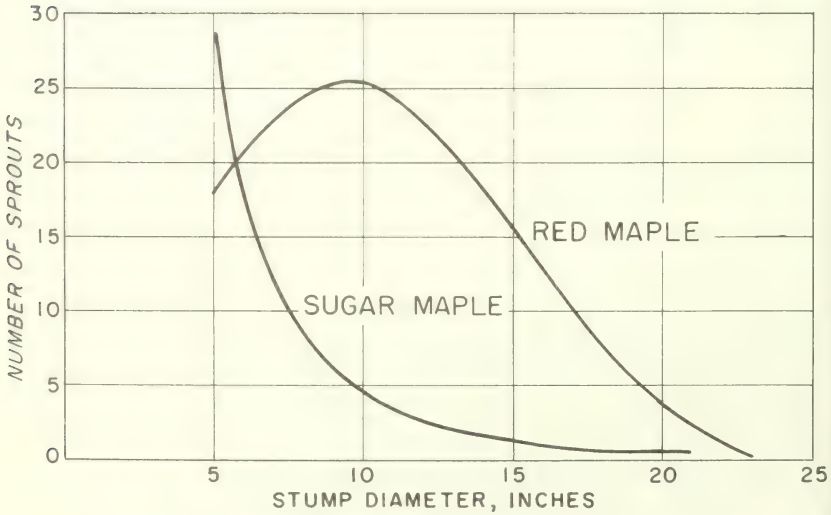


Figure 2. — Relationship of number of sprouts per stump to average stump diameter for red maple and sugar maple.

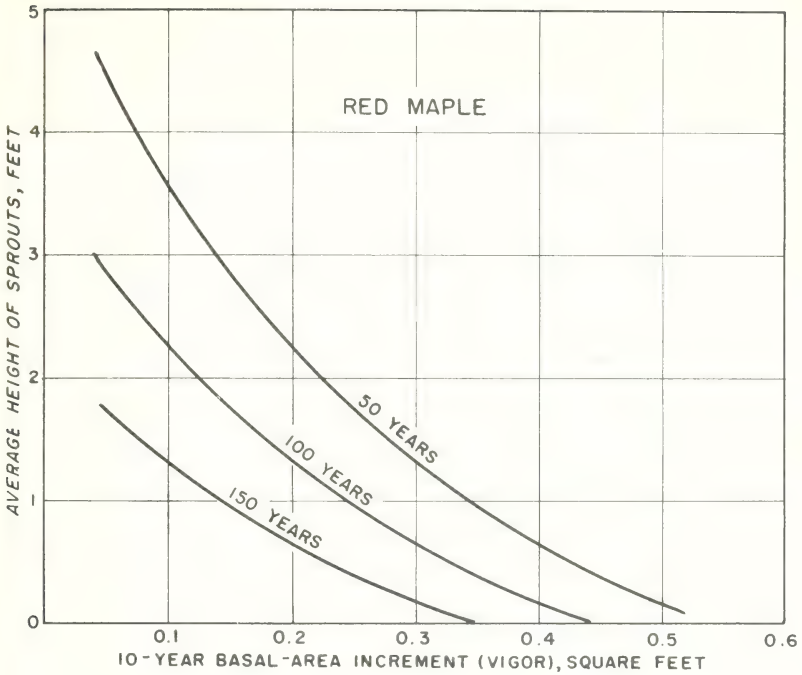


Figure 3. — Relationship of the average height of the three tallest sprouts per red maple stump to 10-year basal-area increment of the parent tree for three tree age classes.

more vigorous trees (see fig. 1) resulted in enough competition to reduce average height of all sprouts.

Sugar Maple

Sugar maple is a considerably less prolific sprouter than red maple. And unlike red maple, sprout numbers did not increase with stump diameter in the lower range of stump sizes. In sugar maple, the number of sprouts decreased rapidly with increasing stump diameter over the entire size range in the sample (fig. 2). This inverse relationship is expressed in the following prediction equation:

$$[IV] \qquad Y = 2.582 - 0.257\ (X_1) + 0.007\ (X_1)^2$$

where Y is the $\log_{10}$ (number of sprouts + 1) and X_1 is the stump diameter. Both coefficients are significant at the 1-percent level. The multiple correlation coefficient is 0.49, and the standard error is 0.093.

The average height of the three tallest sugar maple sprouts was for the most part inversely related to stump diameter. The most accurate equation for predicting sprout height was:

$$[V] \qquad Y = 0.974 - 0.064\ (X_1) + 0.002\ (X_1)^2$$

where Y is the $\log_{10}$ (average height of three tallest sprouts + 1) and X_1 is the diameter of the parent stump. Equation V has both regression coefficients significant at the 1-percent level, a multiple correlation coefficient of 0.590, and a standard error of 0.025.

The general inverse relationship between sprout height and stump size for sugar maple illustrates the same principle revealed by the red maple data: that the older the parent tree, the less vigorous the sprout reproduction. Although stump size proved to have greater predictive value than stump age in sugar maple, this did not negate the age relationship. Possibly the greater tolerance of the sugar maple — its greater capacity to grow in an understory position — accounted for the emergence of stump size as the more important variable in computing the regression for this species.

The stump-diameter/sprout-height relationship for sugar maple is shown graphically in figure 4. The increase in height for stump diameters greater than about 16 inches could be due to sampling variation; we can suggest no other explanation for it.

Paper Birch

The number of sprouts and the average sprout height for paper birch appeared to be influenced by both parent stump diameter and residual basal area. However, the multiple-regression equations did not depict relationships that could be explained biologically. Because no conclusion could be reached, these equations are not presented.

Sprout height did appear to be inversely related to residual basal area. Paper birch is the only species in the study that exhibited this relationship. Because of their intolerance, paper birch sprouts

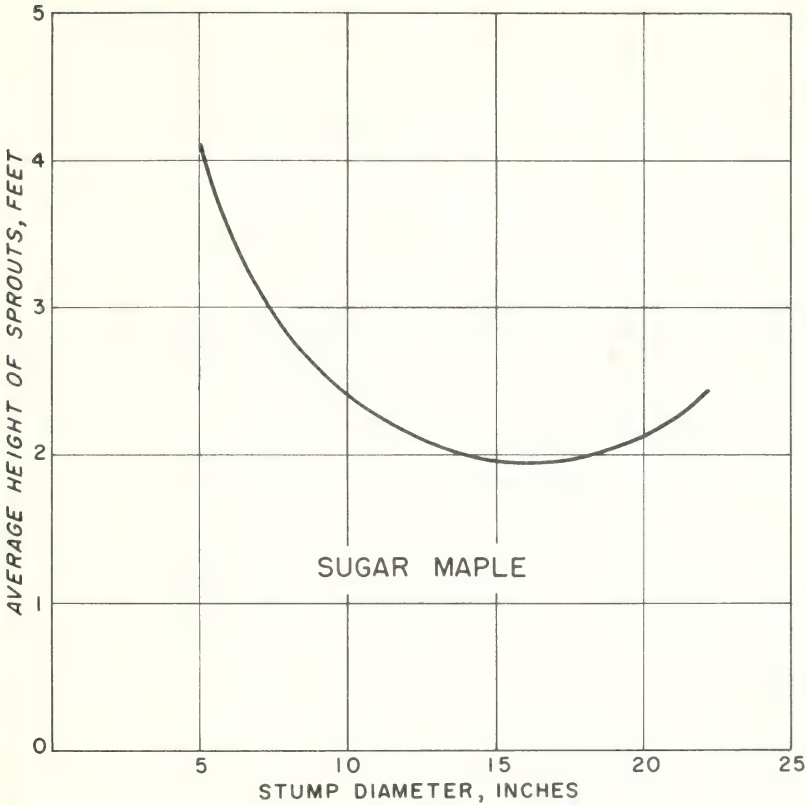


Figure 4. — Relationship of the average height of the three tallest sprouts per sugar maple stump to stump diameter.

may be more sensitive to the shade or other effects of residual trees than are those of red and sugar maples (fig. 5).

Yellow Birch

Yellow birch may be considered as non-sprouting in the White Mountain area. For the areas sampled, only 3 of 44 stumps had sprouts, and only 1 of the 3 stumps had any appreciable number of sprouts.

Figure 5. — Residual basal area had no appreciable effect on number or height of 2-year-old red and sugar maple stump sprouts: A, a sprouting red maple stump in a clearcut area; B, a comparable sprouting stump in a partially cut area.

Discussion and Recommendations

Although the correlations were not exceptionally high, the regression equations presented in this paper appear to be sufficiently accurate to provide useful generalizations about the sprouting of red and sugar maples. Further, the observations on sprouting — or the lack of it — in paper and yellow birches should be similarly useful to forest and wildlife managers.

Small stumps generally produce more sprouts than large stumps. For red maple, the number of sprouts increased as stump diameter approached 9 inches and then decreased at greater stump diameters. In sugar maple, the number of sprouts declined rapidly as stump diameter increased above 6 inches (the minimum size measured). Furthermore, the smaller (sugar maple) or younger (red maple) stumps produced the taller sprouts. Relationships for paper birch were inconclusive, and yellow birch proved to be essentially a non-sprouting species.

Increased vigor of red maple trees, as reflected by 10-year basal-area increment, was associated with heavier sprouting in stumps up to about 16 inches in diameter. However, the average height of red maple sprouts decreased with increasing tree vigor, possibly because of competition among sprouts. Tree vigor did not appear to be an important factor for any species other than red maple.

In paper birch, sprout height tended to decline with increasing residual basal area, but this factor had no discernible effect upon either number or height of the 2-year-old sprouts of red maple and sugar maple. In general, this observation on the maples is in accord with the findings of Little (*4*), who, in a thinning study of coppice oaks 2 inches d.b.h. and smaller, reported sprouting to be only slightly influenced by the surrounding residual stand.

However, moderate to high residual basal areas could be expected to gradually suppress the height growth of sprouts as their age increases beyond 2 years. This expectation is supported by the work of Clark and Liming (*2*), who found that competition from untreated trees did not affect the percentage of girdled trees that

sprouted but did reduce sprout height growth over a 6-year period of observation.

Wildlife managers who wish to induce sprout growth of red and sugar maples can do so by cutting vigorous, small trees. However, after a heavy cutting, stumps of such trees tend to produce fast-growing sprouts that may soon grow beyond the reach of browsing deer. Hence, a more appropriate technique might be crown thinning (or weeding) in immature hardwood stands. This treatment should produce large numbers of sprouts, and the residual stand should gradually suppress their height growth.

Another argument in favor of crown thinning in immature hardwoods is that this technique can be used to accomplish timber management, as well as wildlife management, objectives. In this connection also, Shafer (*8*) has suggested the use of intermediate cuts for integrated timber-browse management of hardwoods in the Northeast.

Where northern hardwood stands in New England are to be managed strictly or primarily for timber, managers are often concerned with suppressing sprout competition — red maple in particular — to favor more desirable regeneration. In these situations, sprouting can be minimized by restricting harvest operations insofar as possible to mature trees or stands, and by chemically treating the smaller stumps and unwanted smaller trees.

■

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by William E. McQuilkin
and Eugene F. McNamara

Tree Planting IN Scrub Oak Areas

AFTER SITE PREPARATION WITH HEAVY EQUIPMENT

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Tree Planting IN Scrub Oak Areas

AFTER SITE PREPARATION WITH HEAVY EQUIPMENT

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A QUESTION OF PLANTING

PENNSYLVANIA'S forests include many acres of a brushland type commonly referred to as scrub oak or bear oak (SAF Type 43[1]). This cover type is found also in parts of New Jersey, Maryland, Virginia, West Virginia, New York, and southern New England. It is a temporary type of the drier sites, and is practically always associated with a history of repeated fires. The distinguishing and usually predominant species is *Quercus ilicifolia.*

Various other shrubs and sprouts of tree species typically are intermixed. In Pennsylvania, the more common tree species include pitch pine (*Pinus rigida*), red maple (*Acer rubrum*), chestnut (*Castanea dentata*), gray birch (*Betula populifolia*), quaking aspen (*Populus tremuloides*), sassafras (*Sassafras albidum*), and the usual upland oaks such as *Q. alba, Q. prinus, Q. coccinea,* and *Q. rubra.* Among the other shrubs, the most characteristic and ubiquitous ones are low-growing blueberries (*Vaccinium spp.*) and sheep laurel (*Kalmia angustifolia*). Bracken fern (*Pteridium aquilinum*) is a common associate.

The soils are stony to varying degrees. Ridges and upper slopes usually are exceedingly stony, with some ledge rock outcropping. Lower slopes and flats range from land with so few stones that clearing and cultivation are possible, to glacial boulder fields and long narrow stringers of boulders where little or no surface soil is present. Most flat and gently sloping areas fall somewhere between these extremes — too stony for agriculture but having sufficient soil to support forest vegetation. In glaciated sections, the land surface in many places is only a skin of humus and soil overlying a stratum of boulders a foot or so thick; beneath the boulders there may be several feet of fairly stone-free mineral soil. Trees can push

[1] Society of American Foresters. FOREST COVER TYPES OF NORTH AMERICA. 67 pp. 1954.

their roots through such boulder layers into the soil below and grow reasonably well — if they escape fire.

The acreage of scrub oak in Pennsylvania has been variously estimated in the past to be as much as 2 million acres. Estimates have varied widely according to the estimator's concept of the type — according to where he drew the line between scrub oak and other sprout hardwood types in which scrub oak was one element. When the estimate was made is also a factor, for the acreage certainly has shrunk as fire protection has improved during the past three or four decades. In 1951 the Pennsylvania Department of Forests and waters estimated, on the basis of a state-wide survey, that the scrub oak type then occupied about 170,000 acres.[2] In this survey, areas having 100 or more stems per acre of commercial species growing above the scrub oak were not considered as of the scrub oak type. This estimate of 170,000 acres is still the best figure available. Later estimates from the Forest Survey of the U. S. Forest Service are based on much less intensive sampling.

These essentially unproductive areas of scrub oak have long been a challenge to foresters. Could commercial timber be grown on them if fire were controlled? Or did the presence of scrub oak indicate sites inherently too poor to produce commercial timber?

During the early days of forestry in Pennsylvania, a number of small planting trials were made in the scrub oak type, the first one of record being in 1911. Although initial survivals often were good, these plantings generally failed because of inadequate site preparation, failure to release the seedlings from the competing brush soon enough and often enough, or the plantings were lost in wildfires. Nothing conclusive was demonstrated, except that scrub oak areas are difficult planting sites. MacIntyre[3] reviewed the situation in 1928 and concluded that planting in this type was not economically feasible.

In 1948, the Northeastern Forest Experiment Station, in cooperation with the Pennsylvania Department of Forests and Waters, started a long-term watershed study in a scrub oak area on

[2] Pennsylvania Department of Forests and Waters. SCRUB OAK IN PENNSYLVANIA. 21 pp., illus. 1951.

[3] MacIntyre, A. C. THE SCRUB OAK TYPE IN PENNSYLVANIA. Unpublished report, Pa. State Bureau of Forestry. 1928.

the Pocono Plateau. The experimental area, comprising about 2,000 acres, was designated as the Dilldown Unit of the Delaware-Lehigh Experimental Forest; it will be referred to hereafter in this paper simply as Dilldown. The study called for conversion of the shrubby cover to a cover of true tree species after a 5-year or longer period for calibrating the watershed. In some places, where sprouts of tree species were abundant, the conversion was to rely on natural growth under fire protection. Elsewhere — on more than one-half the area — conversion was to be accomplished by planting. Experiments were started in 1948 to determine how the planting should be done. The results and implications of those experiments are summarized in this paper.[4]

Beginning in 1955, conversion plantings on the Dilldown watershed, and subsequently in several other locations, were done by methods developed in the experiments. The results in these action programs also will be briefly described.

THE PLANTING EXPERIMENTS

Four major studies and several smaller supplemental experiments were established during the period 1948-53. The four major studies were: (1) preliminary experiments, (2) bulldozer furrow study, (3) rototiller study, and (4) rootrake study. The studies will be described in only a general way, with but little detailed data. The emphasis will be on the practical aspects of the results.

The primary problem in planting in scrub oak is site preparation. With adequate site preparation, the primary variable to be evaluated is species. Those are the main themes throughout this paper.

[4] These experiments have been described and the results have been summarized periodically in a series of publications issued in 1951, 1953, 1955, and 1961 by the Pennsylvania Department of Forests and Waters as Reports Nos. 1, 2, 3, and 4 under the title FOREST AND WATER RESEARCH PROJECT — DELAWARE-LEHIGH EXPERIMENTAL FOREST. Those reports had only a restricted distribution and, furthermore, were oriented to the watershed study. Therefore, this paper, devoted solely to the tree-planting aspects of the project, seems warranted despite some duplication of previously published material.

Preliminary Experiments

This first study, begun in 1948, involved several site-preparation methods, 11 tree species, 2 sizes or ages of planting stock, slit versus center-hole planting, and post-planting release versus no release. The study site represented easier than average planting conditions: almost level ground, relatively few stones, and a relatively low and open stand of brush. Much of the scrub oak was about 3 feet tall.

At that time the difficulties and importance of the site-preparation problem were not fully appreciated, and — by hindsight — the attack on it appears rather inept. The methods tried were (1) hand-made scalps, (2) furrowing with an old-model Killefer fire-line plow, (3) plowing strips with a brush-breaker plow; (4) chopping up the vegetation with a heavy tandem disk; and (5) no site preparation. None of these methods was satisfactory. The machine methods worked to a degree, but considerable supplemental hand work with a mattock was required to prepare suitable planting spots. Hand scalping was utterly impracticable: the ericaceous understory of blueberry and sheep laurel forms an amazingly tough mat of wiry roots and stolons that defies the puny efforts of a man with a mattock. Planting with no site preparation in this root mat also was impracticable.

This first study taught us one important lesson: that our only hope for an effective practical method of mechanical site preparation lay in powerful heavy equipment.

Eight tree species and one mixture of hybrids were used in the study:

Pitch pine — *Pinus rigida*	European larch — *Larix decidua*
Red pine — *P. resinosa*	Red oak — *Quercus rubra*
Scotch pine — *P. sylvestris*	Black locust — *Robinia pseudoacacia*
Jack pine — *P. banksiana*	Hybrid poplars — 5-clone mixture
White pine — *P. strobus*	

In addition, Japanese Larch (*L. leptolepsis*) and Norway spruce (*Picea abies*) were planted in a few plots outside the formally designed experiment.

The seedlings were ordinary nursery stock, and some of the stock was not of good quality because the state nurseries at that time had not fully recovered from the disruptions of the war period. The stock of some species had suffered from too high density in the nursery bed, improper care after lifting, or other mishandling. Differences in stock quality to some degree confounded the species comparisons.

Age or size of stock was less important than the overall quality characteristics resulting from treatment in the nursery. When seedlings were sturdy and in good condition, small stock survived and grew almost as well as larger stock. Seedling survival and later performance did not differ significantly between the two planting methods.

The hybrid poplars survived only a year or two, even on the plowed strips. All the other species, except Norway spruce, demonstrated a capacity to survive satisfactorily and become established in prepared spots or sites. In the small supplemental trial of Norway spruce, which was on plowed strips, about one-half of the seedlings died out after hanging on for a few years in a state of check. And, in this case, the quality of the stock when planted appeared to be good. Although most of the surviving seedlings eventually overcame the checked condition and made more or less normal growth, the overall performance of this species must be rated as poor.

All of the site preparations that broke up and removed the ericaceous root mat around the seedlings permitted satisfactory survival and establishment. Results were somewhat better in the Killefer furrows than in the other treatments, even though these furrows averaged only about 1 foot wide. On the plowed strips, some mortality occurred that apparently was caused by air pockets in the soil where debris had been turned under.

Survival and growth were not markedly increased by the release treatments (cutting overtopping brush during the second and fourth years); most vigorous seedlings were able to get up above the relatively low brush without help. Had the brush been taller and denser, as it is in many scrub oak areas, the losses caused by suppression on unreleased plots doubtless would have been greater.

Bulldozer Furrow Study

This study, begun in 1950, was our first attempt to adapt heavy equipment to the site-preparation job. After some preliminary experimenting with a medium-sized bulldozer, we hired a D7 Caterpillar equipped with a hydraulically controlled standard blade. The objective was to skin off the ericaceous root mat in furrows of sufficient width and depth that trees planted in them could grow without subsequent release.

By tilting and angling the bulldozer blade to the maximum, fairly satisfactory furrows could be made by lowering just the trailing edge of the blade into the ground. Because of the tremendous side draft on the machine, and the tendency for debris to accumulate on the blade, the operator could not keep going ahead continuously., However, he could commonly make runs of 30 to 50 feet or more during which the soil and debris rolled from the end of the blade in a more or less continuous flow similar to the flow from a moldboard plow. Then debris would pile up, or rocks would force the blade out of the ground, and he would have to stop and back up for a fresh start.

Except where the soils were excessively stony, practically continuous furrows that conformed reasonably well to specifications (3 to 4 feet wide and 5 to 8 inches deep) were prepared. The furrows were spaced 8 to 10 feet apart, center to center. We prepared about 47 acres by this method because we wanted a good estimate of costs on a day-by-day production basis. The charge for tractor and operator in 1950 was $9.00 per hour; the site-preparation cost, based on actual operating time, was $13.21 per acre.

One significant observation made during this job was that the skill of the tractor operator is an exceedingly important element in the cost picture. We had two operators, and one could accomplish about twice as much as the other in a given time.

On the basis of their early performance in the preliminary experiments, red pine and Japanese larch were scheduled to be the major species in this planting. However, Japanese larch stock was not available from Pennsylvania nurseries in 1950, so European larch was used instead. The pine and larch were planted by a

Figure 1. — An aerial view in 1965, showing most of the 47-acre planting made in 1950 in bulldozed furrows. Dark strips are red pine and light strips are larch. The strip of about 10 acres in the foregound (marked by dotted line) was prepared with a rootrake and planted in 1953.

mattock-slit technique in alternating 8-row strips (fig. 1). A few strips were planted to jack pine, pitch pine, and red oak.

Survivals at the end of the first summer were 90 percent or better for all species except red oak. The red oak stock was received in poor condition from the nursery. Its survival was about 70 percent the first summer. Considerable mortality occurred during the next year, and only a few of the survivors exhibited normal vigor. Their fate was not followed after 1953. The other species suffered only moderate attrition during the next few years; survivals after 8 growing seasons (the last sampling for survival) were in the range of 75 to 85 percent.

No release cutting of brush was ever done. A few seedlings were shaded out by brush growing out from the sides of the furrows, but most of these were weaklings that grew poorly from the beginning. Occasional seedlings were clipped by rabbits, were killed by sawfly larvae, or died from undetermined causes.

The European larch seedlings both here and in the preliminary experiments varied greatly in vigor. Some were hopeless runts from the start and eventually died. Others did not develop a real leader for several years, and these trees usually remained among the slower growers.

Rototiller Study

In 1951, an entirely different type of machine was tried on about 8 acres — a heavy model Seaman Rototiller. This machine cultivated strips 6 feet wide. The strips were spaced 10 feet apart center to center, some once over, some twice over, and some thrice over with the tiller. On strips tilled two or three times, the vegetation was well macerated and the soil was in good condition for planting. However, fragments of the stoloniferous species remained in the soil, and promptly gave rise to abundant regeneration. After about 3 years, the low cover had regenerated almost completely.

This experience with the rototiller demonstrated again, as in the preliminary experiments, that machinery designed for farm use is not well suited for site preparation in the scrub oak. After this relatively small job, the tines of the tiller were badly worn, and the machine suffered several breakdowns. It simply was not built ruggedly enough to cope with the stones and large scrub oak root crowns.

Japanese larch was the major species used in this planting. Some double-tilled strips also were planted to red pine, jack pine, and pitch pine. Survival and early growth were good for all species. For Japanese larch, the only species planted under all three tillage intensities, both survival and early growth increased with tillage intensity. In 1954, the spread in average survival from once over to thrice over with the tiller was from 72 to 86 percent, and the spread in average height was from 2.4 to 3.1 feet.

Growth rates began to slow down perceptibly during the third and fourth years after planting. Although dry weather may have been a factor in this, the primary cause was believed to be increasing root competition from the regenerated low vegetation. This planting burned out in 1957, so we don't know how well the trees would have grown in the long run.

Rootrake Study

In 1952, after having observed the use of rootrakes for site preparation in the Lake States, we hired one of these rigs for a trial at Dilldown. The machine we obtained was a D6 Caterpillar tractor mounting a 10-foot rake in the same position as a bulldozer blade. The rake consisted of 10 stout teeth spaced 1 foot apart.[5] One advantage of a rootrake over a solid blade is that some combing action is achieved; that is, less soil is picked up when the shrub crowns and ericaceous root mat are removed from a planting patch or strip. Another advantage is that teeth can be forced into stony ground more readily than a blade.

We first tried complete clearing of lanes as wide as the rake (10 feet), but found this to be excessively expensive. We then devised a zig-zag cross pushing procedure that did a rougher but adequate job of clearing lanes about 10 feet wide. With lanes about 10 feet apart, edge to edge, this cost $14.10 per acre in a 10-acre job at the rate of $10.00 per hour for machine and operator. Thus the cost was roughly comparable to the $13.21 per-acre cost for the 1950 bulldozer furrowing when we allow for the $1.00-per-hour increase in equipment rental in 1952.

The site preparation accomplished by the rootrake was considered to be better than that accomplished by furrowing. The lanes were planned to accommodate two rows of trees at 6- by 6-foot spacing. Although seedlings planted in the lanes might be shaded some from one side, the other side would remain open, and there seemed little likelihood that any appreciable number of the seedlings would be seriously suppressed.

Red pine and Japanese larch were planted in the spring of 1953 in alternating 4-row strips (fig. 1, right side). Within lanes, the spacing was roughly 6 by 6 feet; between lanes, the row-to-row distance was some 12 to 15 feet. Early survival and growth were good. Sample tallies in the spring of 1955 showed 83 percent survival for both species; in 1958, after five growing seasons, the survival figures were 80 and 81 percent. Only an insignificant num-

[5] Some models of rootrakes are a combination consisting of a blade with teeth extending below. The rootrake used in this study consisted only of teeth mounted on a supporting bar.

ber of seedlings suffered any suppression from overhanging brush. As in the furrow planting, no release has ever been done.

Other Studies

Besides the four major studies involving mechanical site preparation, we made smaller trials in 1950 of an acre or so where only a herbicide was used, or where no site preparation at all was done.

Of the herbicides available and tried in 1950, only ammate accomplished any substantial reduction of the vegetation. It killed most of the understory and top-skilled the scrub oak and tree sprouts. Tree seedlings planted in spots far enough from large root crowns to escape being overgrown as the regrowth developed grew about as well as where the site had been prepared mechanically.

The planting with no site preparation was spotted into small openings in the scrub oak and taller brush, and no attempt was made to achieve any particular spacing. Trees were placed only in openings at least 5 or 6 feet in diameter. Thus, except for some slight shading by the low-growing vegetation, they were assured of light from above. These trees survived reasonably well but grew poorly. The poor growth is attributed to the root competition associated mainly with the understory vegetation.[6]

However, planting in either living or dead standing brush is an exceedingly tedious and frustrating sort of work, and it requires conscientious effort to do it well. Such planting would never be practicable on a large scale, regardless of how well the trees might grow.

Species Appraisal

Of the species tried at Dilldown, red pine and Japanese larch are definitely the best choices for planting. The two species differ greatly in growth rate, but each has performed well within the limitations imposed by its natural characteristics. Both species

[6] McNamara, E. F., and Irvin C. Reigner. ROOT COMPETITION SLOWS GROWTH OF PLANTINGS IN UNPREPARED SITES IN SCRUB OAK. U. S. Forest Serv. NE. Forest Exp. Sta. Forest Res. Note 54. 3 pp. 1955.

Figure 2. — Japanese larch 12 years after planting in double rows in lanes cleared by rootrake. Central open strip is the 10- to 15-foot space between lanes, occupied by a ridge of debris from the clearing.

survive adequately after planting by routine procedures on prepared sites; both tolerate the rather adverse soil and climatic conditions of scrub-oak areas on the Pocono Plateau; and both have thus far remained free of serious insect or disease pests.

Red pine has been represented in all the studies and has grown about equally well in all of them. The seedlings normally grow slowly for the first few years. In the rootrake study, for example, mean height after 5 growing seasons was 2.9 feet. The growth rate typically increases after about the fifth year and annual height increments of a foot or more become common. In some years the more vigorous trees will put on 2 feet.

No formal sampling to determine mean heights has been done in any of the plantings since 1958. A few sample trees were measured in the spring of 1965 as a check on general estimates by eye. Red pine in the rootrake planting (after 12 years) mostly ran about 10 feet tall. The stronger trees ranged up to 12 or occasionally 14 feet, and the weaker ones down to about 7 feet. Good but not exceptional red pines in the 1950 furrow planting stood 12 to 13 feet tall. In one better-than-average red pine plot planted with 2-2 stock in 1948, most of the trees were 16 to 18 feet tall; one tree measured 19 feet.

Japanese larch is best represented in the rootrake planting. There it averaged 6 feet tall after 5 growing seasons, and has continued to grow very well. After 12 years, the trees that made up the silhouette of the stands were mostly 20 to 25 feet tall, and occasional trees ranged up to 30 feet or more (fig. 2). Although this species does not exhibit the extreme variation of European larch, considerable variation in size and vigor were evident. Trees in the 15- to 20-foot class were not uncommon, and others in the 10- to 15-foot class were occasionally encountered.

Among other species, white pine, scotch pine, pitch pine, and European larch merit some consideration.

White pine, tried only in the preliminary experiments, performed rather erratically: some trees grew well, but a good many grew poorly. It has the further disadvantages of being subject to damage by the white-pine weevil and by blister rust, and seedlings are a favorite food for deer. Under conditions of light deer pressure at Dilldown, white pine was the only species in our plantings that was hurt appreciably by deer browsing.

Scotch pine, also used only in the preliminary experiments, has survived and grown very well; in growth it has slightly exceeded red pine. However, scotch pine can be recommended only with reservations because, in this country, it seldom continues to grow well into pole and sawlog sizes. In fact, some of our trees in 1965 — 17 years after planting — appeared to be slowing down. Many of them had lost their leaders (presumably ice and snow damage) and apparently were not capable of developing a strong replacement (fig. 3).

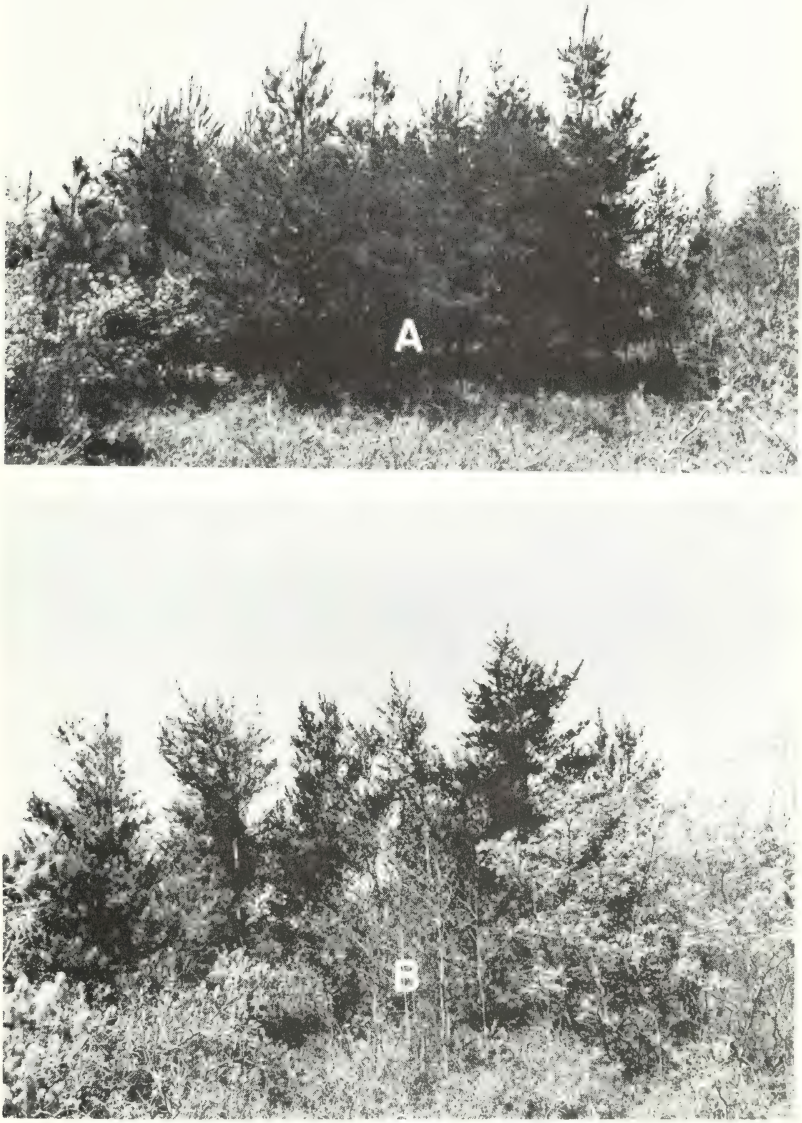

Figure 3. — Two 25-tree plots of scotch pine in the 1948 planting as they appeared in 1965. A, trees still growing fairly well; tallest one is 22 feet. B, most of trees becoming flat-topped; tallest one is 19 feet.

Figure 4. — European larch in the 1950 planting in bulldozed furrows. The two trees in back are among the better ones — 20 to 21 feet tall in 1965. The two trees in the adjacent furrow in front are weaklings 8.5 and 10.5 feet tall (tips marked by arrows).

Pitch pine is an enigma. Probably the species includes genetic stock capable of yielding progeny of good form, but such stock has not been identified and utilized for propagation purposes. None of the pitch pine planted at Dilldown is developing in good form. The best pitch pine is in the bulldozer furrow planting. These trees grew fairly well at first, averaging 6.3 feet tall after 8 years — almost 2 feet taller than red pine in the same planting. Their form looked promising up to that time, but as the trees have emerged above the level of the brush, their terminals have become more crooked and height growth has slowed down. Until pitch

pine seedlings of genetic strains of good form are available from the nurseries, extensive planting of this species would not seem advisable.

European larch, as has often been observed, is an exceedingly variable species, apparently because of diverse genetic origins represented in the imported seed. In our substantial planting of this species in bulldozed furrows, about 25 percent of the trees (based on rough estimates) have done reasonably well and, at the other extreme, at least 25 percent of the trees were congenital runts that have either died or are dying out. The rest of the trees are coming along, but relatively slowly; they seem destined to occupy intermediate and suppressed positions in the final stand. However, the best of the European larch in 1965 was only about 20 feet tall (fig. 4). So, even though 3 years older, these trees had not attained the height of many of the Japanese larches. The latter species seems unquestionably to be the better of the two larches for planting under the conditions represented at Dilldown.

None of the other species tried in the studies are suitable for planting on scrub oak sites. Jack pine, although promising at the start, was not windfirm after it grew above the level of the surrounding brush. Norway spruce in our one small trial went into prolonged check from which only about 50 percent of the trees eventually recovered and grew. Given good planting stock, red oak perhaps would perform better than it did in our experiments; but the scrub oak soils could hardly be expected to support good, quality growth of any hardwood. Black locust and hybrid poplars definitely have no place in scrub oak planting.

CONVERSION PLANTING ON THE WATERSHED

By 1955, the calibration phase of the watershed study had been completed, and the rootrake method had been demonstrated as a practicable way to prepare the less stony areas for planting. The species comparisons, even then, pointed rather definitely to red pine and Japanese larch as first choices, with scotch pine and European larch as the most promising alternates.

Based on a planting survey of the watershed, some 1,100 acres were scheduled for conversion. However, this survey revealed that much more of the area than had previously been realized was so stony that mechanical site preparation was not feasible. These portions supported scrub oak vegetation and, superficially, they appeared plantable. But the humus mat overlaid a practically complete layer of stones a foot or so thick. Beyond a certain density and thickness of this stone layer, a rootrake (or bulldozer) cannot be operated effectively for site preparation. Only about 335 of the 1,100 acres were mapped as suitable for planting.[7]

The plantable areas on the watershed were prepared by a rootrake technique and planted by the Pennsylvania Department of Forests and Waters during the years 1955-57. Only about 285 of the 335 acres mapped as plantable actually were planted; the other 50 acres were in small islands that were by-passed either because of adequate stocking with native trees, or because of excessive stoniness.

A rootraking technique that differed radically from the cross-pushing procedure used in the experimental planting was devised and used in most of the conversion planting. In this later technique, as described by McNamara,[8] series of small, separate planting patches are cleared, rather than lanes. From a given starting point, the tractor progresses backward across the area to be worked, in the following manner:

First, the operator engages the teeth and moves forward until a full load has been accumulated — perhaps 15 to 20 feet. Next, he reverses from the load across the cleared ground and continues 20 feet or so into undisturbed area. Here, he again engages the teeth and moves forward until this load is at the starting point of the first cleared patch. Then he reverses as before across the last cleared patch into undisturbed area, and repeats the process.

The result is a line of cleared patches, each separated from the

[7] Experiments have since been undertaken to develop procedures for direct seeding the stony areas after reducing the brush with herbicides. These offer considerable promise of success. Also, recent re-examinations of the watershed indicate that much of the area originally scheduled for conversion is developing enough natural tall growth so that seeding or planting will not be necessary for purposes of the watershed study.

[8] McNamara, E. F. CONVERTING SCRUB OAK AREAS. Pa. Forests 52 (2): 22, illus. 1962.

Figure 5. — A site prepared for planting with rootrake by the technique developed on the Dilldown watershed. This area is on State Forest land in Dauphin County, Pennsylvania.

next on either end by a mound of soil and debris (fig. 5). Other lines of patches are prepared parallel to the first, spaced about 10 feet apart edge to edge. Each patch is 10 feet wide (the width of the rake), 10 to 15 or more feet long, and will accommodate 4 to 8 trees at spacings of approximately 6 feet.

This method of preparation was devised and adopted for reasons of economy. The cross-pushing procedure, when tried in the conversion job, was costing more than twice as much as in the experimental job because the operators were less skillful, the soil conditions were somewhat more difficult, and the rental rate for equipment had increased ($11.00 an hour for a D6 outfit). The

Figure 6. — Red pine planted on the watershed in 1956, photographed in 1965. Trees are mostly 8 to 10 feet tall. This is the site of the first rootrake preparation on the watershed; it was done with the cross-push technique, clearing a continuous lane.

new procedure was simpler to execute because the tractor movements were almost all straight back and forth, with very little turning or other maneuvering required. And, compared to the lanes in the experimental job, the area cleared per acre was less by the amount of space occupied by the mounds of debris. So, the work progressed somewhat faster on an acre basis. But despite the more efficient procedure, costs on the conversion job ran somewhat higher than on the experimental job, probably because ground conditions were generally more difficult. The average cost on 245 acres worked by this procedure was $17.81 per acre.

The lines of separate cleared patches provide somewhat less planting space per acre than cleared lanes. Another undesirable feature is the mounds of debris between the patches: These impede planting to some degree because the men have to scramble over or around them as they move from one patch to another. Nevertheless, this method of site preparation is the most practicable one yet devised for planting the scrub oak lands. It permits the planting of 600 to 800 trees per acre in positions where they will grow without requiring any subsequent release. The number of trees planted will vary according to how well the planters utilize the available space: by placing some trees at or in the toes of the mounds, and by judicious tightening of the spacing where this will

Figure 7. — Scotch pine, planted in cleared patches in 1957, emerging above the brush in 1965. Most of the trees are 9 to 10 feet tall; occasional ones are up to 12 feet tall.

permit planting another tree or two in a patch, 800 trees per acre are possible.

The distribution of the trees within a planted area is, of course, not in the regular pattern of old-field planting, but it is such that we believe closed stand conditions will eventually develop. In general, if the distance between lines of patches does not exceed 10 feet, the distance between clumps of trees should seldom exceed 15 feet.

Red pine, scotch pine, and European larch were the main species used in the conversion planting. Japanese larch, which would have been preferred over the European species, was not available from Pennsylvania nurseries when needed in 1957. The planting, done by contract, cost about $20 an acre. With trees figured at the nursery price of $6 per thousand, the total planting cost for site preparation, planting, and stock was about $44 an acre.

Survival and growth of the trees have generally been good. Survivals for different lots of stock or locations at the end of the third growing season ranged from 83 to 91 percent. Sample measurements in the 1956 planting of red pine and the 1957 planting of scotch pine showed heights predominantly in the range of 8 to 10 feet for both species in the spring of 1965. Two-foot internodes for 1964 were not uncommon. Barring fire, the conversion plantings show excellent promise of developing into thrifty, well-stocked coniferous stands (figs. 6 and 7).

OTHER CONVERSION PLANTINGS

Pennsylvania foresters, particularly those responsible for management of the State Forests, watched with interest as success became evident in the site-conversion experiments at Dilldown. The rootrake offered, for the first time, a machine and a technique that seemed practical and economically feasible for converting at least some of the State's unproductive brushland areas to productive forest. Moreover, the rootrake technique would substantially reduce the risk of disastrous wildfires for a number of years because of the repeated breaks in continuity of the fuel.

The first brushland conversion plantings by the rootrake tech-

Figure 8. — Japanese larch 2 years after planting in a patch cleared with a rootrake; on State Forest land, Dauphin County. Although the brush here is relatively tall, the larches give promise of emerging above it without difficulty.

nique on areas other than Dilldown were begun in 1957. During that year and since, 567 acres on State Forest land in three forest districts, 47 acres on a municipal watershed, and 20 acres of private land have been prepared and planted. In addition, 140 acres of States Forest land were prepared in the fall of 1965 for planting in 1966.

The practice on all these jobs has been basically the same as in the watershed-conversion planting at Dilldown; that is, to clear lines of small separate patches, usually in the fall, followed by hand planting of 700 to 800 trees per acre the next spring. However, different makes of rootrakes, different makes and sizes of

tractors, different operators of varying degrees of proficiency, differences among the sites, and differences among planters and in number of seedlings planted per acre all conspired to bring about considerable variation in per-acre costs.

The species planted have been Japanese larch predominantly (fig. 8), plus smaller quantities of red pine, pitch pine, Austrian pine, and Norway spruce. Early survivals have ranged from very good to poor. Some of the poorer survivals can be explained by frost damage, an unusually dry summer after planting, fall planting, and use of planting stock that was not in optimum condition. Cost, survival, and other data extracted and summarized from District Foresters' reports on the State Forest plantings are given in table 1. The survival data should be viewed as merely indicative because we do not know the method or intensity of sampling, and we do not know whether the sampling was done the first fall after planting, the next spring, or later.

One private landowner in Monroe County rootraked and planted about 20 acres of scrub oak land in 1960 and 1961. Japanese larch, red pine, and Norway spruce were planted, larch making up 78 percent of the total. We do not have definite cost and survival data. The costs apparently were about in line with those on the State jobs. Survival both years was reported as excellent.

It is of passing interest that this planting qualified for payments under the Agricultural Conservation Program at the approved rate of $19 per acre for site preparation by rootrake.

In the fall of 1964, the Bethlehem Authority rootraked 47 acres of brushland on their holdings in Monroe County. They used a TD-18 tractor, a bigger machine than was used on the other jobs. Site-preparation costs were $28.68 per acre, which the supervising forester felt could be substantially reduced after the tractor operator had gained more experience. About 600 red pine and Japanese larch seedlings per acre were planted in 1965 at a per-acre cost of $16.91. This was a lower rate of planting and a lower planting cost than in any of the other jobs. No survival data are yet available.

By and large, the costs have been higher and seedling survivals somewhat lower in these other conversion plantings than in those at Dilldown. Perhaps this was to be expected because the whole

Table 1. — Cost, survival, and other data on rootrake plantings on State Forest land in Pennsylvania

Location	Year of planting	Area planted	Species	Cost per acre		Survival
				Rootraking	Planting	
		Acres				*Percent*
Dauphin County, District 18	1957, 1958, 1960, 1963, 1964	503	Japanese larch	$18.26[1] ($17.95-18.85)	$40.67[1] ($27.73-54.82)	79[1] (60-95)
Pike County, District 19	1961, 1962	15	Japanese larch Red pine Pitch pine Norway spruce	21.60	33.68	85[2]
Snyder County, District 7	1960	49	Japanese larch Austrian pine	36.73	40.02	70 40

[1] First figures given are weighted averages; figures in parenthesis show the range in values.
[2] 1961 planting only.

procedure was new to both supervisory personnel and tractor operators; they had to gain experience on the job. And the competence of the tree planters probably did not average as high as in the Dilldown crew. Also, considerably more than the recommended 700-800 seedlings per acre were planted in some of the jobs, which would increase planting costs.

Survivals are known to have been adversely affected by drought and frost in some places. Fall planting was done on at least one occasion, and stock that had been heeled-in over winter or longer also was used on two jobs. These practices probably accounted for some of the poorer survivals.

Conversion planting in the scrub oak type will never be easy or inexpensive. But the rootrake technique for site preparation does provide a way to plant such areas successfully at a cost that can be borne, particularly where other values in addition to timber are involved on public lands. One compensation for the relatively high initial costs is that, ordinarily, no subsequent release treatments will be required. Costs can be expected to decline somewhat as supervisory and operating personnel gain experience. And good planting stock, properly handled and planted at the proper time, should assure a high percentage of success.

DISCUSSION

Successful conversion of scrub oak or other brushland types by planting depends upon a practicable method of site preparation. Herbicides are not the answer because planters cannot work effectively in standing dead brush. Furthermore, if only herbicides were used, the tough mat of ericaceous roots and the layer of rocks that often lies at the soil surface would be additional impediments to efficient planting. These obstacles must be broken up and moved aside by mechanical means so that planters can work in cleared spaces. There may still be rocks to contend with, but since the rocks in many places are concentrated near the soil surface, they can be loosened and moved sufficiently to permit planting.

Furrowing with a heavy bulldozer (D7 or equivalent) was the first practicable site preparation method developed in the Dilldown experiments. The 47-acre plantation growing there today demon-

strates its efficacy. This plantation was given no release after planting. However, a few trees were suppressed by brush leaning over from the sides of the furrows. In brush types containing a large proportion of tall-growing, heavy-foliaged sprouts of tree species, greater losses than were experienced at Dilldown would occur unless release treatments were made.

Site preparation by clearing lanes or patches with a rootrake is a better method because the cleared spaces are wider than the bulldozed furrows. All trees planted in these clearings have open space on one side at least, and very few are likely to be suppressed, even by brush that grows taller than typical scrub oak.

Although continuous cleared lanes would be preferable, lines of separate patches prepared by the method developed in the Dilldown watershed planting is a practical concession to cost realities. This method provides space for planting 600 to 800 trees per acre in a pattern that should result in stand closure as the trees reach pole size.

Where planting costs of $50 or so per acre can be justified for converting brushlands to coniferous forest, the rootrake method of site preparation is recommended wherever soil conditions and terrain will permit operation of this equipment. Where a rootrake is not readily available, and where tall-growing, heavy-foliaged tree sprouts are not predominant in the brushy growth, bulldozer furrowing might be considered as a second-choice method.

Mechanical site preparation and planting are, of course, not feasible in much of the brushland of the Poconos and the Northeast as a whole. Rough or steep terrain rules out tractor equipment in many places. Furthermore, thin soils over residual rock, or excessive glacial deposits of loose rock, often rule out mechanical site preparation as a practical measure. The presence of brushy growth does not mean that a site is plantable. Therefore, one of the first tasks facing a land manager when considering conversion planting is to determine the location and amount of area that actually is plantable. Only then can he begin to plan intelligently in terms of acres and costs.

SUMMARY

Tree planting experiments in the scrub oak type of the Pennsylvania Poconos are described. The first experiments in 1948, with hand tools and farm machinery, demonstrated that adequate site preparation could be accomplished only by use of heavy equipment. During the years 1950-53, a D-7 bulldozer, a heavy rototiller, and a rootrake mounted on a D-6 tractor were used in planting trials of 10 to 47 acres.

Fairly good site preparation was possible by furrowing with a bulldozer; trees planted in the furrows generally came through without later release. Double tilling with the rototiller also resulted in good site preparation; but this method was not practical because of the need for two passes over each planting strip, and also because the machine was not rugged enough to stand up under the rigorous operating conditions of the stony brushlands. The rootrake proved to be best suited for the job.

After several procedures were tried with the rootrake, a technique was devised by which separate patches, each 10 by 15 to 20 feet, were cleared in lines about 10 feet apart. Usually 6 to 8 trees were planted in each patch. The planted trees have grown well without follow-up release treatments, and are expected to create closed-stand conditions as they reach pole size.

Red pine and Japanese larch are the most highly recommended species for such plantings. Scotch pine also does well during the first decade or so.

After the original trial of the rootrake in 1953 demonstrated its merits, about 285 acres were prepared by rootraking and were planted in 1956 and 1957 as part of a watershed study. At the equipment rental rates prevailing at that time, the rootraking cost $17.81 per acre. Total planting costs (preparation, seedlings from a state nursery, and planting labor) were about $44 per acre.

Since 1957, almost 800 more acres of brushlands in the Pocono region have been similarly prepared and successfully planted on state forest, municipal watershed, and private land.

This method of site preparation and planting can be recommended wherever the terrain and stone content of the soil will permit a rootrake to be effectively operated.

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